PROCEEDINGS OF THE 4TH INTERNATIONAL CIVIL ENGINEERING & ARCHITECTURE CONFERENCE

Volume 2: Architecture

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HASAN BASRİ BAŞAĞA
VOLKAN KAHYA
VEDAT TOĞAN

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Volume 2: Architecture

Editors

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PREFACE

The 4th International Civil Engineering & Architecture Conference (ICEARC'25) aimed to bring together academics, researchers, and practitioners in the fields of civil engineering and architecture from across the globe. Held in Trabzon, Türkiye on May 17–19, 2025, the conference served as a dynamic platform to review recent achievements, share emerging developments, and address both current and future challenges in these disciplines.
ICEARC'25 has once again demonstrated its truly international character, drawing over **500 participants from 33 countries**. The conference hosted **421 research presentations** delivered in **59 parallel sessions**, and provided participants with excellent networking and collaboration opportunities. In addition to the technical sessions, **four dedicated workshops**—focusing on contemporary themes such as sustainable buildings, hybrid structures, and advanced materials—offered attendees practical insights and knowledge exchange in specialized areas.
The **Proceedings of the 4th International Civil Engineering and Architecture Conference** includes all the accepted and presented papers, compiled in two volumes:

- **Volume 1: Civil Engineering**, comprising 303 papers under major categories such as Structural Mechanics, Earthquake Engineering, Hydraulics & Fluid Mechanics, Geotechnics & Soil Mechanics, Transportation, Structural Materials, Hydrology & Water Resources, Construction Management, and Waste Management.
- **Volume 2: Architecture**, featuring 118 papers grouped under topics such as Architectural Philosophy, Design & Practice, Architecture, Conservation & Restoration, Urban Planning & Landscape, Architectural Engineering, and Interior Design.

We are sincerely grateful to all authors for their valuable contributions. The papers included in these volumes were rigorously reviewed by field experts, and only those that were accepted and presented at the conference have been published. We extend our deepest appreciation to the reviewers for their meticulous evaluations, which significantly contributed to the quality of this publication.
We would also like to express our gratitude for the institutional support provided by **Karadeniz Technical University** and **the Chamber of Civil Engineers (Trabzon Branch)** of the **Union of Chambers of Turkish Engineers and Architects**. We sincerely thank our sponsors:

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Our special thanks go to the **Mayor of Trabzon Metropolitan Municipality**, **Mayor of Ortahisar Municipality**, and **Mayor of Yomra Municipality** for their valuable support.
We also acknowledge the outstanding efforts of the organizing committee, the student volunteers, and all the moderators who chaired our sessions with professionalism and dedication. Their contributions were instrumental in the success of ICEARC'25.
Finally, the conference concluded with a memorable **social tour to the iconic Sümela Monastery and Uzun Göl**, offering participants a taste of the region's rich cultural and natural heritage.
We look forward to welcoming you again at **ICEARC'27**.

Editors

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The analysis of usage metal powder waste as cement substitute in concrete

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Abstract.
Purpose: The importance of a sustainable waste management approach is increasingly growing in order to protect natural resources and reduce waste. The limited nature of natural resources has brought forth the alternative of using recycling practices, particularly as a potential source of raw materials in the construction industry. The usage of metal powder waste in the construction sector not only ensures the safe disposal of waste but also reduces the consumption of raw materials and energy. In this way, environmental problems are prevented and economic benefits are achieved in terms of costs.
Study design/methodology/approach: In this study, metal powder waste materials have been investigated as substitute materials for cement to reduce the negative environmental impacts occurring during the cement production phase. Three different metal powder wastes, considered to improve the life cycle of concrete, have been used as cement substitute materials. The effects of boron oxide, aluminum oxide, and zinc oxide powder wastes, usage in varying proportions as metal powder waste, on the physical and mechanical properties of concrete have been experimentally investigated in a laboratory environment and how these materials alter the performance of concrete has been observed.
Findings: Based on the results obtained depending on the type and proportion of the metal powder waste used, it has been observed that alternative sources can be utilized as cement substitute materials, and these alternative sources can enhance the life cycle assessment of concrete.
Originality/value: By using metal production waste dust as recycling material, natural resources can be protected and alternative materials that can provide economic benefits can be developed.

Keywords: Waste material; Metal waste; Life cycle assessment; Sustainability; Concrete; Cement; Substitute materials.

1.Introduction

The long-standing need for urbanization throughout human history has brought with it the issue of depleting natural resources. As a lasting solution to this problem, the concept of sustainability has come to the forefront.

Sustainability can be defined as a form of development that allows current resources to be utilized without harming them, ensuring their availability for future generations. It is well known today that natural resources are rapidly depleting, and it is becoming increasingly difficult to compensate for this loss. In this context, the understanding of environmental sustainability has gained significant importance. Sustainability, while crucial in many fields, holds particular importance in the construction sector.

Following the Industrial Revolution, rapidly growing populations in urban areas have made it necessary for urban planning to align with sustainability principles. This has introduced various criteria into design processes. Examples include ecological transportation alternatives, wastewater treatment and reuse, rainwater harvesting for reuse, and the use of environmentally friendly local materials. A major reason for the rapid deterioration of ecosystems today is the production and use of synthetic materials not found in nature, which cause significant environmental damage during their lifecycle. This demonstrates that ecological design cannot be considered independently of material selection (Aytıs & Polatkan, 2010).

Concrete, the most commonly used building material in the world, is preferred in sustainable design due to its durability, longevity, local availability, thermal mass capacity, low toxic gas emissions as a finished product, recyclability, lack of contribution to the urban heat island effect, versatility, and aesthetic appeal (Tuğrul & Sev, 2015).

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At the same time, concrete constitutes the largest share of construction and demolition waste in the construction industry. Most aggregates and the cement produced are used in concrete. By its nature, cement is an energy-intensive material that emits significant amounts of CO_2. Aggregate extraction depletes soil and involves heavy transportation processes. It is estimated that approximately 8% of global CO_2 emissions result from concrete production. It is clear that the production and use of concrete have a considerable environmental impact. The construction industry plays a decisive role in the environmental effects—both positive and negative—and the concept of sustainability, a multidimensional goal in the concrete industry, requires a range of approaches (Arıoğlu et al., 2004).

The careful and intelligent use of concrete can provide environmental benefits. By utilizing cement-reducing materials, proper mix ratios, and recycled or waste materials, concrete can be made both sustainable and durable (Arıoğlu et al., 2004).

In this study, in order to reduce the amount of cement used in concrete production and to develop a sustainable alternative material, the use of metal powders—industrial by-products—as a cement substitute was investigated. Mechanical and physical tests were carried out on three different types of concrete produced with metal waste powders, and the impact of these powders on concrete performance was evaluated.

2. Methodology

In order to determine whether aluminum oxide, zinc oxide, and colemanite powders—used as industrial waste—possess pozzolanic properties, preliminary tests were conducted on these metal waste powders. Based on the results of these preliminary tests, the material characteristics and concrete mix ratios were established. Four different cement replacement ratios were determined: 10%, 20%, 40%, and 50%. Including the control sample, a total of four different types of concrete were produced. These concrete types are: control concrete, aluminum oxide-replaced concrete, zinc oxide-replaced concrete, and colemanite-replaced concrete.

2.1 . Materials

2.1.1 . Cement

In the experimental study, CEM I 42.5R type cement, produced in accordance with the TS EN 197-1 standard, was used. Consistency determination, setting time determination, and specific gravity tests were conducted in accordance with the relevant standards.

2.1.2 . Aggregate

In the experimental study, specific gravity, moisture content determination, water absorption, and sieve analysis tests were performed on the aggregates in accordance with TS EN 1097-6 and TS EN 933-1 standards, respectively (Fig. 1). Based on these test results, the amount of material passing through each sieve and the fineness modulus of the aggregates were evaluated.

The fineness modulus is a numerical value that provides information about the granulometric composition of an aggregate. It is calculated by subtracting the cumulative percentage retained on each sieve from 100, summing these values, and dividing the total by 100 (Özkul et al., 1999). The granulometry of the aggregate blends used in the concrete was selected to fall between the A and C curves, as specified in the TS 802 “Concrete Mix Design Calculation Principles” standard (Fig. 2).

Fig. 1. Specific gravity and sieve analysis of aggregates

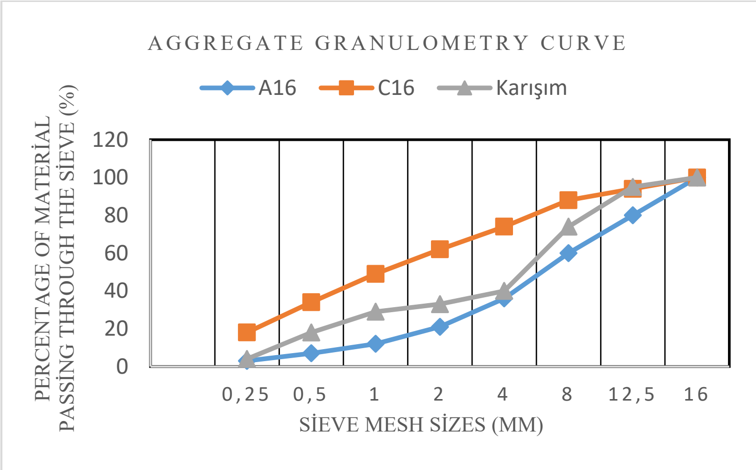

Fig. 2. Aggregate granulometry curve.

2.1.3 . Metal Production Waste Powders

In the study, aluminum oxide, zinc oxide, and colemanite products, which are metal production waste, were used in powder form. Preliminary tests were conducted to investigate the specific gravities and pozzolanic activities of these materials.

The pozzolanic activity test was carried out according to the TS 25 standard. According to the standard, the 7-day compressive strength of the produced samples should be at least 4 N/mm². The produced samples were kept for 24 hours at a room temperature of 23±2°C, covered with a glass plate. After 24 hours, without removing the molds, the samples were further kept in an oven at 55±2°C for 6 days. The samples were then left in the room for 4 hours until they reached room temperature (Fig. 3). Once the samples reached room temperature, compressive and bending strength tests were conducted using a Form-Test Seidner brand test device with a 200 kN capacity (Fig. 4).

Fig. 3. Samples kept in molds and removed from molds in the pozzolanic activity test.

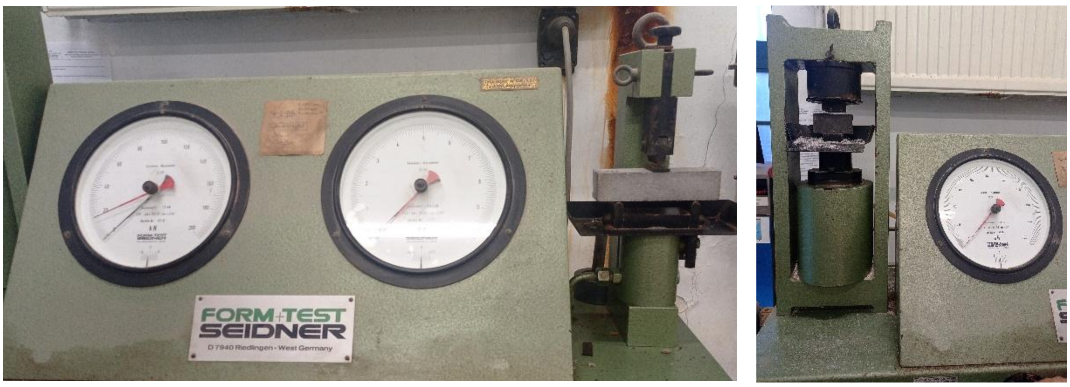

Fig. 4. Flexural strength tests conducted to determine pozzolanic properties.

2.2 . Methods

2.2.1 . Mechanical tests

The load-bearing properties of construction materials are determined based on their mechanical properties. In the study, bending tensile, compressive, and static elasticity tests were conducted to measure the mechanical properties of the different types of concrete samples produced. In these tests, the static elasticity modulus was applied on the 28th day of curing, while the bending tensile and compressive tests were performed on the 7th, 28th, and 90th days of curing.

2.2.1.1. Flexural Strength Test

For the determination of flexural strength (Rf), prism-shaped samples with dimensions of 4x4x16 cm were prepared in accordance with the standard and tested using a 100 kN capacity universal testing machine, in compliance with the TS EN 12390-5 standard (Fig. 5). The measurement of the square cross-section of the prismatic samples (b) was taken, and the distance between supports (l) was recorded. The sample was placed between the supports and broken by applying a load at the midpoint of the sample. The load value (Ff) was recorded in Newtons. The flexural strength was calculated using Equation 1.

$$\mathrm{Rf} = \frac{1{,}5 \text{ x } \mathrm{Ff} \text{ x } \mathrm{l}}{\mathrm{b}^3} \tag{1}$$

Fig. 5. 100 kN capacity testing machine used for the flexural strength test.

2.2.1.2. Compressive Test

The prismatic samples with dimensions of 4x4x16 cm, broken during the flexural test, were also tested for compressive strength (Rc) using a 100 kN capacity universal testing machine, in accordance with the TS EN 12390-3 standard (Fig. 6). The failure load (Fc) was recorded in Newtons and was calculated using Equation 2.

$$\mathrm{Rc} = \frac{\mathrm{Fc}}{\mathrm{b}^2} \tag{2}$$

Fig. 6. 100 kN capacity testing machine used for the compressive strength test.

2.2.1.3. Static Elasticity Modulus Test

Cylinder samples with dimensions of 7.5x15 cm were produced from all concrete mixes, and deformation tests were conducted. For the static elasticity modulus (Es), the samples cured for 28 days at a temperature of 20±1°C were fixed within a frame (Fig. 7). An extensometer with a precision of 0.01 mm was placed on the frame. The force (F) values corresponding to the deformation (Dl) under load were recorded using a universal testing machine.

In the stress (σ)-deformation (ε) graphs, the initial tangent of the curve, where stress and deformation are linear, was used. The slope of the tangent in this region was calculated using the least squares method. Stress, strain, and elasticity modulus were calculated using Equation 3, Equation 4, and Equation 5.

$$\sigma = \frac{\mathrm{F}}{\mathrm{A}} \tag{3}$$

$$\varepsilon = \frac{\Delta l}{\mathrm{lo} - \Delta l} \tag{4}$$

$$\mathrm{Es} = \frac{\sigma}{\varepsilon} \tag{5}$$

Fig. 7. Static elasticity modulus test setup.

2.2.2. Physical tests

As part of the physical tests, capillary water absorption, weight-based water absorption, and apparent porosity tests were conducted on the concrete samples at the 28th and 90th days of curing.

2.2.2.1. Capillary Test

The capillarity coefficient (N) was determined in accordance with the BSI Standards Publications 2011b standard, for samples that were dried at a temperature of 70±5 °C and then cooled to room temperature (23±2 °C). Prismatic samples, for which the contact surface area (As) was measured, were placed in the experimental setup under laboratory conditions, with their dry weight (mdry,s) and contact time (tso) recorded. The samples were positioned in such a way that the determined surface would be in contact with water (Fig. 8). Subsequently, at specified time intervals, the surface water on the contact area was wiped off, and weight changes (mso,s) were monitored. The values obtained from these measurements were used to calculate using Equation 6.

$$N = \frac{\text{mso,s} - \text{mdry,s}}{\text{As}\sqrt{\text{tso}}} x10^{-6} \quad (6)$$

Fig. 8. Capillary water absorption test setup.

2.2.2.2. Apparent Porosity and Water Absorption by Weight Test
Apparent porosity (Sh) is the ratio of the void volume of the material to its apparent volume. It was calculated by dividing the difference between the material's saturated weight (ms) and its dry weight (md) by the difference between the material's saturated weight (ms) and its weight in water (mh), as given in Equation 7.

The weight-based water absorption (Sk) ratio was calculated by dividing the difference between the material's saturated weight (ms) and dry weight (md) by the dry weight (md), as shown in Equation 8. Measurements were taken using an experimental setup constructed in accordance with the BSI Standards Publications 2006 standard (Fig. 9).

$$\text{Sh} = \frac{ms - md}{\text{ms} - \text{mh}} x\ 100 \quad (7)$$

$$Sk = \frac{ms - md}{md} x\ 100 \quad (8)$$

Fig. 9. Water absorption by weight and visible porosity test setup.

3. Result and discussion

3.1. Mechanical tests results

3.1.1. Compressive strength and flexural strength of concrete

Compressive and flexural strength tests were conducted on the 7th, 28th, and 90th days, and the values from the tests are presented in the graphs (Fig. 10, Fig. 11).

If we assume that the strength of the concrete mixes on the 7th day provides information about early strength, we observe that the concrete with colemanite substitution has the earliest strength, followed by the aluminum oxide and zinc oxide substituted concretes in sequence.

Considering the compressive and flexural strength values of all concrete types, it is observed that the AL%20 sample from the aluminum oxide substituted concretes has the highest value on the 90th day, the Ç%40 sample from the zinc oxide substituted concretes has the highest value on the 28th day, and the KL%10 sample from the colemanite substituted concretes has the highest value on the 90th day. Furthermore, the sample closest to the control sample is the KL%10.

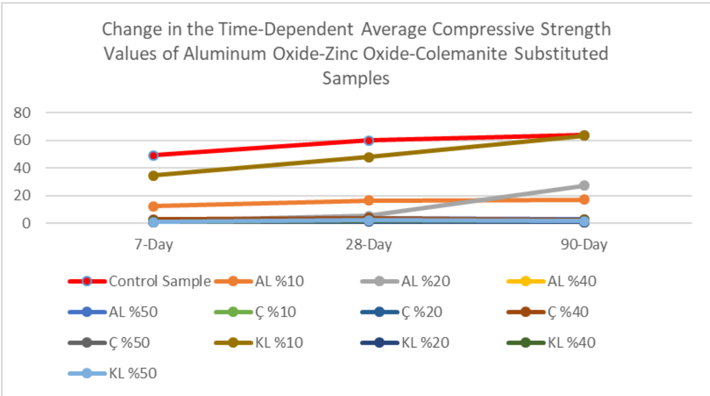

Fig. 10. Compressive strength variation graph of Aluminum Oxide-Zinc Oxide-Colemanite substituted samples.

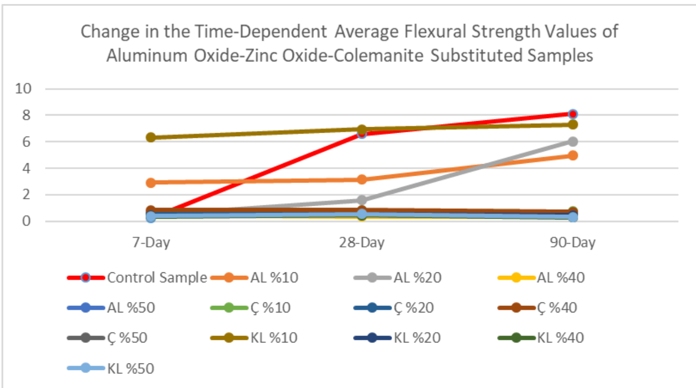

Fig. 11. Flexural strength variation graph of Aluminum Oxide-Zinc Oxide-Colemanite substituted samples.

3.1.2. Static Elasticity Modulus of concrete

Cylinder samples with dimensions of 7.5x15 cm were produced from all concrete mixes, and a deformation test was performed on the 28th day of curing.

When the stress-strain measurements were plotted on a graph, the highest values, as shown in the graph, were recorded for the colemanite substituted samples, followed by the aluminum oxide substituted samples, and the zinc oxide substituted samples (Fig. 12). The KL%10 sample achieved the highest value and was the closest to the control concrete.

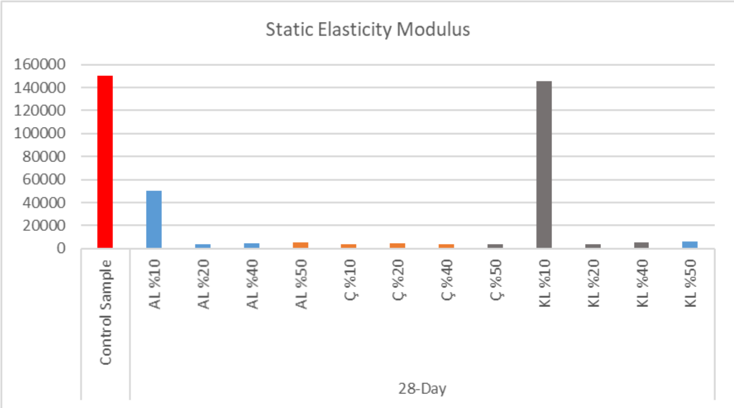

Fig. 12. Elastic modulus values of Aluminum Oxide-Zinc Oxide-Colemanite substituted samples.

3.2. Physical tests results

3.2.1. Capillary, Apparent Porosity and Water Absorption by Weight of concretes

When the results of capillary water absorption, water absorption, and apparent porosity were examined, it was observed that as the substitution ratio increased in all samples, the capillarity coefficient also increased, as shown in Fig. 13.

The increase in the capillarity coefficient, which is related to the material's pore structure, indicates that as the substitution ratio in the material increases, the pore ratio in the samples also increases..

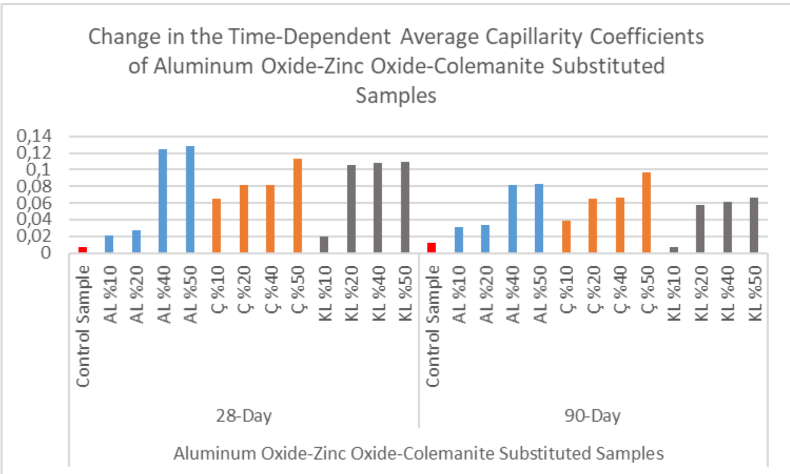

Fig. 13. The change in the average capillarity coefficients of Aluminum Oxide-Zinc Oxide-Colemanite substituted samples.

In the samples, a decrease in capillarity coefficients over time is observed. This decrease is attributed to the fact that, at the end of hydration, each component of the cement creates different hydration products (C-S-H, Calcium-Silica-Hydrate), which fill the voids in the concrete. Additionally, it is believed that the metal waste powders added as substitutes increase the impermeability of the concrete. These reactions are thought to prevent the formation of capillary pore spaces within the concrete, and as a result, the capillary water absorption is lower over time, as shown in Fig. 14 and Fig. 15.

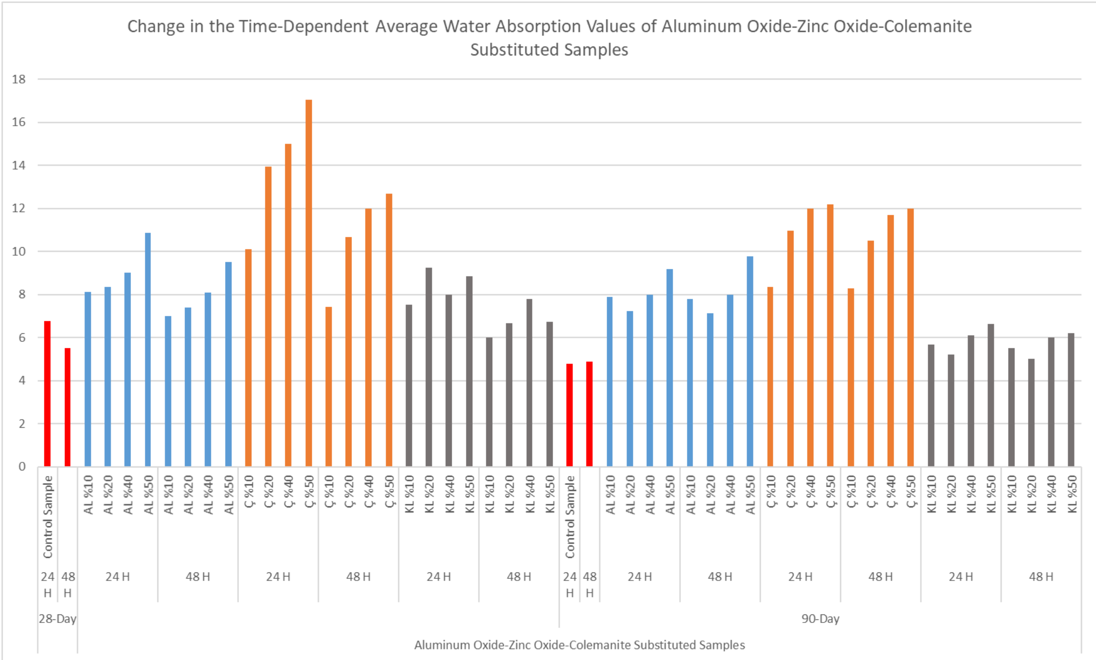

Fig. 14. The change in the average water absorption values of the samples with aluminum oxide-zinc oxide-colemanite substitution.

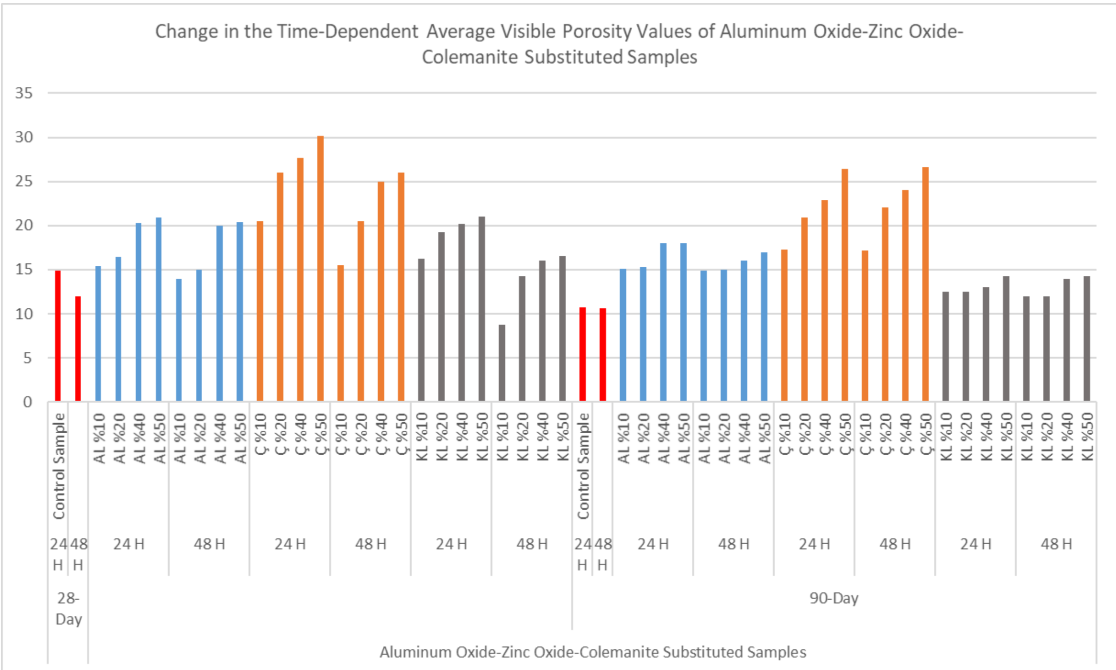

Fig. 15. The change in the average visible porosity values of the samples with aluminum oxide-zinc oxide-colemanite substitution.

4. Conclusions

In this study, the importance of sustainability through the reuse of recycled materials is emphasized. In this context, aluminum oxide, zinc oxide, and colemanite substituted concretes were produced to investigate the effect of using metal powders, which are production waste, as cement substitutes on the physical and mechanical properties of concrete. The waste metal powders used in the production of these concretes were substituted for cement in different proportions, and the effect of various metal powders and their proportions on the durability and strength properties of concrete was examined.

- When examining the experiments conducted to investigate the physical properties, it is understood that the samples with 10% KL substitution improved the physical properties of the concrete.
- When examining the experiments conducted to investigate the mechanical properties, it is observed that the samples with 10% KL substitution have values similar to or close to the control samples.
- As the substitution ratio of metal waste powders increases, a decrease in mechanical strength is observed.
- When the experimental data is examined, it is considered that concretes with colemanite and aluminum oxide substitution could be suitable for use as a load-bearing material according to TS 500 standards. However, other samples that do not fall under the load-bearing class, considering their physical and mechanical properties, might be suitable for use as cement substitutes in plaster and mortar production.
- The use of metal production waste powders as recycled materials can conserve natural resources and provide economic benefits.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Enhancing thermal comfort and energy-saving potential of the buildings with multiple-layered phase change material

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Abstract. The increasing population, rising living standards, and growing use of indoor spaces have significantly increased energy demand in the construction sector. This situation highlights the need for innovative building envelope design to reduce energy consumption and promote environmental sustainability. In this context, phase change materials (PCM), known for their high thermal energy storage capacity, emerge as an environmentally friendly solution. Key factors affecting the thermal comfort and energy consumption of buildings include the type, thickness, melting temperature, and number of layers of PCM. Although most of the research is focused on the use of single-layered PCM in exterior wall design, research on multiple-layered PCMs is quite scarce. Thus, the current study aims to assess the use of multiple-layered PCM in the exterior wall design of an educational building located in different climate zones of Türkiye. Simulations were conducted to evaluate the impact of multiple-layered PCM and PCM-thermal insulation (TI) combinations on thermal comfort, energy-savings, and construction costs during both summer and winter periods. Istanbul and Erzurum were chosen to represent temperate-humid and cold climates, respectively. Simulation results revealed that wall sections combining PCM and TI had higher thermal performance and energy-savings compared to those with only PCM. Multiple-layered PCM provided better thermal comfort with lower energy requirements for summer and winter periods, compared to single-layered PCM. Wall sections with multiple-layered PCM (3 PCM layers, each 30 mm) and TI (30 mm) could achieve energy savings of up to 3.93% in heating energy consumption and 2.77% in cooling energy consumption, compared to single-layered PCM.

Keywords: Multiple-layered phase change material; Thermal insulation; Heating and cooling; Thermal comfort; Energy-saving

1. Introduction

In Türkiye, approximately 33% of the total energy consumption occurs in the residential sector. Therefore, the development of technologies that enhance energy efficiency in residential buildings is of great importance (Terhan, 2021). Energy efficiency refers to the reduction of energy consumption without compromising the level of comfort. Considering the correlation between energy consumption and the level of development, energy efficiency is not only a key component of environmental sustainability but also a critical factor in economic development (Terhan et al., 2023).

The building envelope, which consists of external components such as walls, roofs, and windows, is one of the primary sources of thermal energy losses. Among these, walls play a critical role in energy efficiency by accounting for approximately 25% to 30% of the total thermal energy loss (Abanda & Byers, 2016). A thermally optimized building envelope design contributes significantly to the reduction of both heating and cooling loads. In this context, one of the innovative and increasingly applied solutions in building envelope design is the integration of "thermal energy storage systems."

Phase change materials (PCM) are innovative substances employed in the thermal energy storage systems of buildings (Beltran & Martinez-Gomez, 2019). These materials transfer the stored thermal energy to the indoor environment in a controlled manner, thereby enhancing indoor thermal comfort. Consequently, they offer significant potential for reducing the heating and cooling energy demands of a building (Sivanathan et al., 2020).

Conventional thermal insulation materials (TI) enhance the thermal resistance of the building envelope by limiting heat transfer between the interior and the external environment (Al-Homoud, 2005). The combination of PCM-TI improves the overall thermal performance of buildings and enables more stable indoor thermal comfort levels (Alizadeh & Sadrameli, 2019). A review of the existing literature reveals that the majority of studies have focused on single-layered PCM applications. These studies often assess performance based on PCM with a fixed

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thickness and a single melting temperature. However, multiple-layered PCM applications offer the potential to regulate heat flow across the building envelope more effectively, significantly reducing thermal loads. Various studies have demonstrated that, depending on the thermophysical properties of the building envelope and the type, thickness, and melting temperature of the multiple-layered PCM and TI used under different climatic conditions, energy savings in heating loads of approximately 2.26–27% and in cooling loads of approximately 8.54–38% can be achieved (Arıcı et al., 2022; İlgar & Terhan, 2024; Asghari et al., 2024; Refahi et al., 2024; Rehman et al., 2021; Dardouri et al., 2023). To fill the current knowledge gap in the literature, the aim of this study is to comprehensively examine the effects of using multiple-layered PCM in the external wall design of an educational building located in two different climate region of Türkiye, in terms of energy efficiency, indoor thermal comfort, and construction cost during both summer and winter periods. Istanbul and Erzurum were selected to represent temperate-humid and cold climate zones, respectively. It is anticipated that the use of multiple-layered PCM could significantly contribute to environmental sustainability by reducing building energy consumption.

2. Methodology

2.1. Description of the Simulated Building

A basic single-story education building model (500 cm x 400 cm x 300 cm) was designed for the simulation (Fig. 1). Because the building model consisted of a single zone, there were no inner walls, and all of the exterior walls were modelled identically. The building has a terrace roof. The west wall was equipped with a wooden door measuring 90 cm wide and 220 cm high. In the current study, the south wall of the building was equipped with a window 400 cm in length and 150 cm in height. The distance between the window bottom and floor was 80 cm. The glass was an air-filled double glass with an overall heat transfer coefficient (U) of 2.8 W/m^{2}K, solar heat gain coefficient of 0.7, and visible transmittance of 0.8.

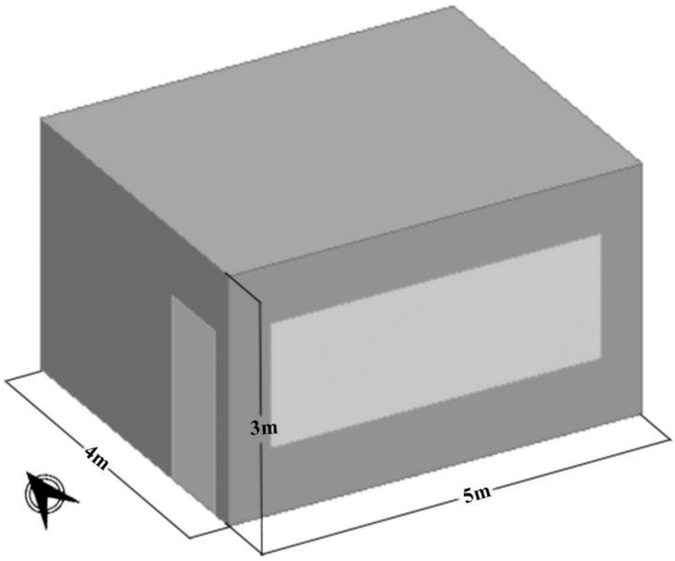

Fig. 1. Geometrical model of the education building analysed

The type and thickness of the materials in the building envelope have been designed in accordance with the thermal conductivity coefficients specified in TS 825 (2013). The details of the building envelope are provided in Table 1, and the thermophysical properties of the materials used are given in Table 2.

Table 1. Details of the building envelope layers

Building Envelope	Layers (from inside to outside)
Roof	20 mm cement-based plaster, 120 mm reinforced concrete slab, 30 mm cement screed, 50 mm thermal insulation, waterproofing, and gravel roofing
Reference wall	20 mm plaster, 30 mm PCM, 240 mm aerated autoclaved concrete and 20 mm plaster
Exterior wall with integrated thermal insulation	20 mm plaster, 30 mm PCM (up to three layers), 240 mm aerated autoclaved concrete, 30 mm TI, 20 mm plaster

Table 2. Thermophysical properties of the selected materials

Material	Density (kg/m³)	Thermal conductivity (W/mK)	Water vapor diffusion resistance (μ)
Cement-based plaster	2000	1.6	15/35
Aerated autoclaved concrete	500	0.15	5/10
Thermal insulation (Glasswool)	32	0.04	1

In this study, the PCM used was directly selected from the database of the DesignBuilder® software (BioPCM® M27/Q21). The thermophysical properties of the PCM are summarized in Table 3. Based on findings from a previous study, the optimal melting temperature of the PCM was determined to be 21 °C for winter, as lower outdoor temperatures allow for more efficient phase transition between melting and solidification, and 27 °C for summer conditions. The lowest heating and cooling energy demands were achieved when the PCM layer was placed on the interior side of the wall section and the TI layer on the exterior. The most effective configuration in terms of maintaining indoor thermal comfort and maximizing energy savings was identified as using 30 mm thick PCM and 30 mm thick TI (Yemenici & Barış, 2024). Therefore, to evaluate the effects of PCM layering on indoor thermal comfort, total energy savings, and construction costs, 30 mm thick PCM was applied on the inner side of the wall section, and 30 mm thick TI was positioned on the outer side in PCM-TI integrated wall configurations.

Table 3. Thermophysical properties of the PCM

Thermophysical properties		Values
Density (kg/m³)	Solid form	880
	Liquid form	760
Thermal conductivity (W/mK)	Solid form	0.2
	Liquid form	0.15
Specific heat (J/kgK)		2000

In this study, two different combinations of material layering have been developed. The wall containing a single-layered PCM (Fig. 2Ref) is defined as the reference wall, and its details are provided in Table 1. To determine the optimal number of PCM layers, the following approach was used:

- The PCM (up to three layers) was placed in the innermost layer of the walls
- The PCM (up to three layers) was placed in the innermost layer, and TI was placed in the outermost layer

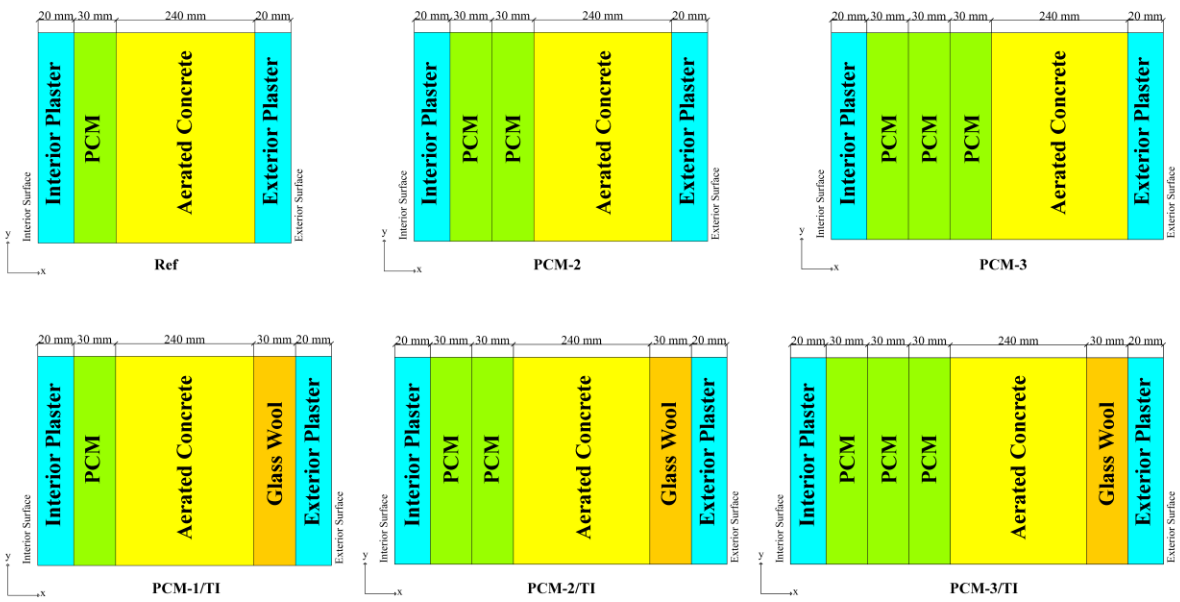

Fig. 2. Simplified drawing of wall sections simulated in the study

The wall sections were coded in [PCM-a] or [PCM-a/TI] format. PCM and TI represent phase change material and thermal insulation, respectively. "a" represents the number of layers of PCM.

2.2. Simulation Details

The analyzed building was intended for educational purposes, with working hours from 09:00 to 16:00. The building's occupancy rate was fixed at 0.55 occupants/m^2. Metabolic rates depend on the activities of the occupants in the education building. Furthermore, the use of equipment was entered into the simulation based on weekly usage rates. An illumination level of 3.4 W/m^2–100 lx of was taken into consideration, during working hours.

As an exterior temperature of 18 °C can maintain the inside at a comfortable temperature of 24 °C, hence, the heating or cooling requirements for any place are usually calculated according to this exterior baseline temperature (Menyhart & Krarti, 2017). The time-dependent variation of the outdoor temperature for the representative cities from January 20-22 and July 20-22 is shown in Fig. 3 respectively. According to this, the outdoor air temperatures in the cities located in two different climate zones are either below or above the reference temperatures. As a result, heating and cooling requirements arise to ensure sufficient thermal comfort. Since the winter and summer seasons represent the maximum heating and cooling energy requirements, respectively, the study focuses on the winter and summer periods, with the goal of reducing heating and cooling energy demand (Arumugam et al., 2022).

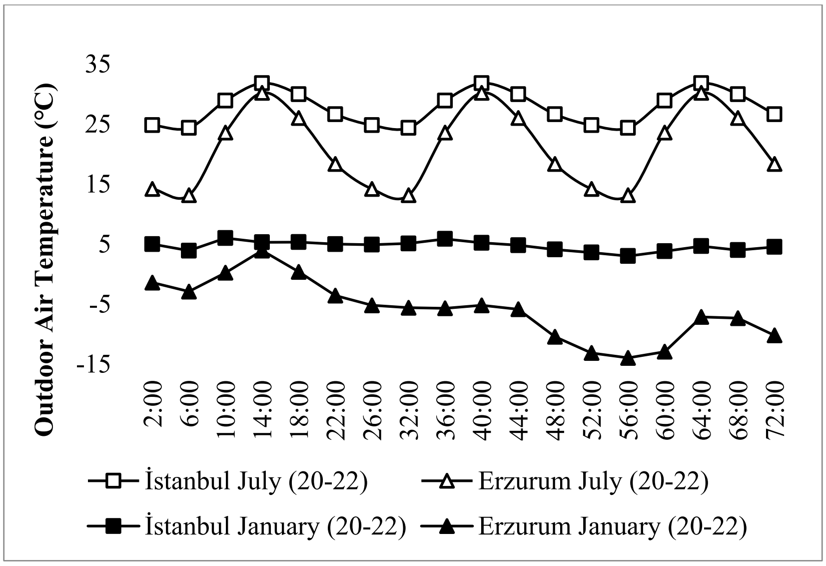

Fig. 3. The outdoor air temperature-time graph for the representative cities

The thermal comfort range was defined as 19 °C for the heating period and 26 °C for the cooling period. Accordingly, mechanical systems are activated only when the indoor temperature falls below 19 °C or exceeds 26 °C. The heating demand of the building is met through a natural gas-based system, while the cooling demand is fulfilled using an electrically powered system. All heating, cooling, and ventilation requirements are provided by mechanical systems, and the impact of natural ventilation was excluded from the simulations by setting it to "off." DesignBuilder® software was used for the simulations. To accurately simulate the phase change process of the PCM, a computational technique known as the "Finite Difference Calculation Method" was selected (U.S. Department of Energy, 2021)

The effects of multiple-layered PCM and TI integration on the thermal performance of the building envelope were assessed by considering indoor temperature reduction (ITR) values. The term "ITR" describes the decrease in the maximum interior temperature of the simulated building (with multiple-layered PCM and PCM+TI) compared with the reference building (without PCM and TI). The mechanical systems were turned off during the ITR calculation to mitigate the risk of changing the thermal performance of the building envelope.

The effects of the multiple-layered PCM and TI on the energy performance of buildings were determined by considering the annual energy savings. The annual energy savings is the amount of energy saved when PCM and TI are incorporated into a building envelope. The annual energy saving, as a ratio (ESR), was calculated to represent the percentage of energy saved by incorporating the PCM and TI, according to Equation (1):

$$ESR = \frac{\text{EC (without PCM / TI)} - \text{EC (with PCM / TI)}}{\text{EC (without PCM / TI)}} \text{ x } 100\ (\%) \tag{1}$$

Where EC is energy consumption (kWh). The ESR and EC values were determined when the mechanical system was active between 07:00 and 24:00 with 100% efficiency and was inactive between 00:00 and 07:00.

The economic viability of wall sections incorporating PCM-TI combinations, designed for different climatic zones of Türkiye, was assessed by considering two key indicators: energy cost savings (ECS) and payback period (PP). Initially, ECS was calculated in accordance with Equation (2) (M'hamdi et al., 2022):

$$ECS = (\mathrm{ES_{summer}} * \mathrm{EC}) + (\mathrm{ES_{winter}} * \mathrm{NC}) \tag{2}$$

ES_{summer} and ES_{winter} (kWh) represent the difference between the annual total cooling and heating energy consumption of the building with simulated alternative wall sections compared to that of the reference wall section. EC denotes the electricity cost, while NC symbolizes the natural gas cost. According to the Turkish Statistical Institute (TÜİK, 2022), the annual average electricity cost in Türkiye is 139.1 kuruş/kWh, and the natural gas cost is 29.5 kuruş/m³.

PP (year) obtained from different PCM-TI combinations in the simulated buildings was calculated according to Equation (3):

$$PP = \frac{[(\mathrm{C_{PCM}} * \mathrm{V_{PCM}}) + (\mathrm{I_{PCM}} * \mathrm{W_{PCM}})] + [(\mathrm{C_{TI}} * \mathrm{V_{TI}}) + (\mathrm{I_{TI}} * \mathrm{W_{TI}})]}{\mathrm{ECS}} \tag{3}$$

C_{PCM} and V_{PCM} represent the cost (TL/kg) and volume (m³) of the PCM, respectively, while I_{PCM} indicates the installation cost (TL/day) and W_{PCM} denotes the number of workers required for PCM installation (Table 4). Similarly, C_{TI}, V_{TI}, I_{TI}, and W_{TI} refer to the cost, volume, installation cost, and number of workers required for the installation of the TI material, respectively. During the calculation of installation costs, it was assumed that the reference building with dimensions of 500x400x300 cm, can be completed in one working day by two workers, whereas the building with integrated PCM-TI requires two working days in total, requiring each worker to work one full day.

Table 4. Parameters used in ECS and PP calculations

Parameters	Values
PCM Cost (TL/kg)	30 mm: 68.82
TI (glass wool) Cost (TL/kg)	30 mm: 84.00
PCM-TI Volume (m^3)	30 mm: 1.3806
PCM-TI Area (m^2)	46.02
PCM Production Facility	Kocaeli (Coral)
TI Production Facility	Adana (İzocam)
Daily Wage of a Worker (TL/gün)	2500

2.3. Climate Conditions

In this study, Istanbul, representing the temperate-humid climate characteristics, and Erzurum, representing the cold climate region of Türkiye, were selected. Hourly environmental conditions, such as temperature, solar radiation, atmospheric humidity, and wind speed, are available in the DesignBuilder® software database. These data were validated by comparing them with the data provided by the Turkish State Meteorological Service (İl ve İlçeler İstatistikleri, 2024).

Table 5. Solar radiation intensities and sunshine durations in selected cities

	Months												kWh/ m^2-year	Altitude	Sunshine (h/day)
Cities	1	2	3	4	5	6	7	8	9	10	11	12			
İstanbul	41	56	95	129	166	180	184	161	127	83	50	36	1389	40	5.9
Erzurum	70	91	132	138	162	181	193	174	142	103	68	56	1511	1890	6.7

The solar radiation intensities and sunshine duration data for the selected cities were obtained from the Türkiye Solar Atlas (Türkiye Güneşlenme Potansiyeli Atlası, 2010), which was prepared by the Meteorological Service of Türkiye (Table 5).

Istanbul represents the 2nd (temperate-humid) climatic region and is under the influence of the Mediterranean, Marmara, and Black Sea climates. In Istanbul, summer is hot and dry, and winter is warm and rainy. The annual average temperature is 16.4 ºC, and the average number of rainy days is 116.5. In addition, strong winds are effective during certain periods in Istanbul (İl ve İlçeler İstatistikleri, 2024). The annual total solar radiation intensity is 1389 kWh/m^2, and the average daily sunshine duration is 5.9 hours (Türkiye Güneşlenme Potansiyeli Atlası, 2010).

Erzurum is located in the 5th climate region and has the coldest climate conditions in Türkiye. Summer is warm and dry; winter is very cold and snowy; and spring is rainy. The lowest average temperature is -20 ºC. Snowfall usually starts in October and continues until late April. The annual average temperature is 5.8 ºC, and the average number of rainy days is 122.1. Harsh climatic conditions are further exacerbated by winds (İl ve İlçeler İstatistikleri, 2024). The annual total solar radiation intensity is 1511 kWh/m^2, and the average daily sunshine duration is 6.7 hours (Türkiye Güneşlenme Potansiyeli Atlası, 2010).

3. Results and Discussion

3.1. Effects of PCM Layers on the Thermal Performance of the Building Envelope

Fig. 4 shows the indoor temperature reduction for three peak days in January and July, to determine the effect of the number of PCM layers on the thermal performance of building envelopes with integrated PCM and PCM-TI.

According to Fig. 4a and 4b, the highest indoor temperatures in both climate regions were observed between 14:00-18:00, while the lowest indoor temperatures were recorded at 06:00. According to Fig. 4c and 4d, the highest indoor temperatures across all climate regions were detected between 14:00-16:00. For the three peak days in January, the highest indoor temperature of the reference building was recorded in Istanbul (13.40 ºC). During the midday hours, when solar radiation is at its peak, the indoor temperatures of reference buildings were lower than those of buildings with integrated PCM. On the same dates, the lowest indoor temperatures of the reference buildings during the night were 5.12 ºC in Istanbul and -7.06 ºC in Erzurum. For the three peak days in July, the highest indoor temperature in the reference building was recorded in Istanbul at 38.86 ºC. During the night, the indoor temperatures of reference buildings with single-layered PCM were lower than those of buildings with multiple-layered PCM, for the three peak days in January, while they were higher for the three peak days in July. In other words, the building envelope with the most significant temperature fluctuations throughout the day was the reference wall section with single-layered PCM.

The integration of multiple-layered PCM in the interior region and TI in the exterior region of the reference building's wall section results in a decrease in indoor temperature reduction (ITR). In other words, multiple-layered PCM prevents sudden temperature changes in the external environment from affecting the indoor environment, allowing users to feel thermally more comfortable indoors. The multiple-layered PCM and TI in the building envelope prevent sudden temperature fluctuations in the external environment from impacting the indoor environment, enabling users to feel thermally comfortable indoors.

During the midday hours, when the highest outdoor temperatures are experienced during both winter and summer, integrating a three-layered PCM into the inner section of the building envelope and TI into the outer section (PCM-3/TI) provided a higher percentage of ITR compared to the reference wall and sections with only multi-layered PCM in all climate regions. In the winter period, the three-layered PCM provided an ITR of 0.38 ºC in Istanbul and 0.33 ºC in Erzurum, and adding TI to these sections in the outer region resulted in higher ITR values (0.51 ºC and 0.49 ºC, respectively).

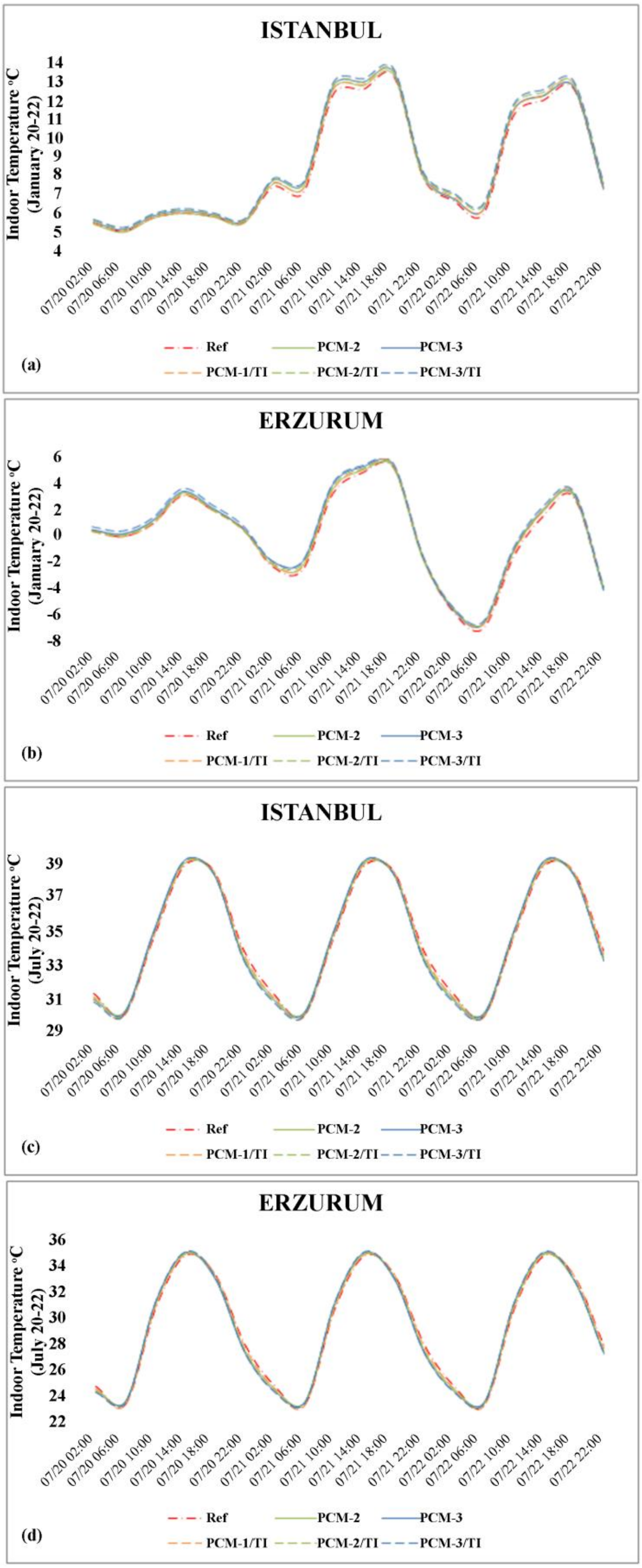

Fig. 4. The reference, indoor temperature reduction for three peak days in January and July of buildings with PCM and PCM-TI integrated: (a) Istanbul (January 20-22); (b) Erzurum (January 20-22); (c) Istanbul (July 20-22); (d) Erzurum (July 20-22)

In the summer period, increasing the number of PCM layers also increased the ITR. When TI was integrated, increasing the number of PCM layers resulted in a more effective ITR, similar to the effect observed in buildings with PCM integration. When the number of PCM layers was increased to three (PCM-3), it provided an ITR of 0.56 ºC in Istanbul and 0.64 ºC in Erzurum compared to the reference building. With the integration of TI (PCM-3/TI), a constant ITR was obtained in Erzurum, while a higher ITR value of 0.60 ºC was achieved in Istanbul.

The higher ITR values obtained in both the PCM-a and PCM-a/TI integrated wall sections, compared to the reference building, can be explained by Fourier's Law. According to Fourier's Law, integrating materials with low thermal conductivity into the building envelope prevents heat from transferring from the more intense environment to the less intense one, thereby increasing the thermal resistance of the building envelope and enabling the maintenance of comfort conditions indoors (Garrido et al., 2001). However, the ITR values obtained in the PCM-a section are lower than the ITR values achieved in the PCM-a/TI section in both climate regions.

In conclusion, increasing the number of PCM layers significantly contributes to the improvement of thermal comfort by reducing ITR. The integration of multiple-layered PCM into the building envelope helps stabilize indoor conditions by balancing external temperature variations. This is particularly effective in climates where temperature reduction during the day is significant. In winter, it prevents sudden indoor cooling, thus reducing heating demand, while in summer, it mitigates overheating, thereby reducing cooling loads. The integration of TI into the building envelope ensures the controlled release of heat stored by the PCM, further diminishing the impact of sudden temperature changes on indoor conditions. In this context, the results obtained in this study indicate that increasing the number of PCM layers directly affects ITR, and, when used in conjunction with TI, this effect is further enhanced.

In this study, the ideal section for winter and summer periods was identified to be the three-layered PCM in the PCM-a/TI wall section, providing the highest thermal comfort. Literature studies have identified the ideal sections for wall configurations containing PCM in the inner and outer regions and TI in the outer region as follows: two-layered PCM for Kocaeli (Türkiye) (Arıcı et al., 2022), three-layered PCM for the inner region in İzmir (Türkiye) (Ilgar & Terhan, 2024), and two-layered PCM for both inner and outer regions in Kansas City (USA) (Asghari et al., 2024). Indeed, these findings align with the data presented in the literature.

3.2. Effects of PCM Layer on the Energy Savings of the Building Envelope

Fig. 5 shows the annual total heating and cooling energy consumption for buildings with PCM and those with PCM-IY integrated walls during the winter and summer periods.

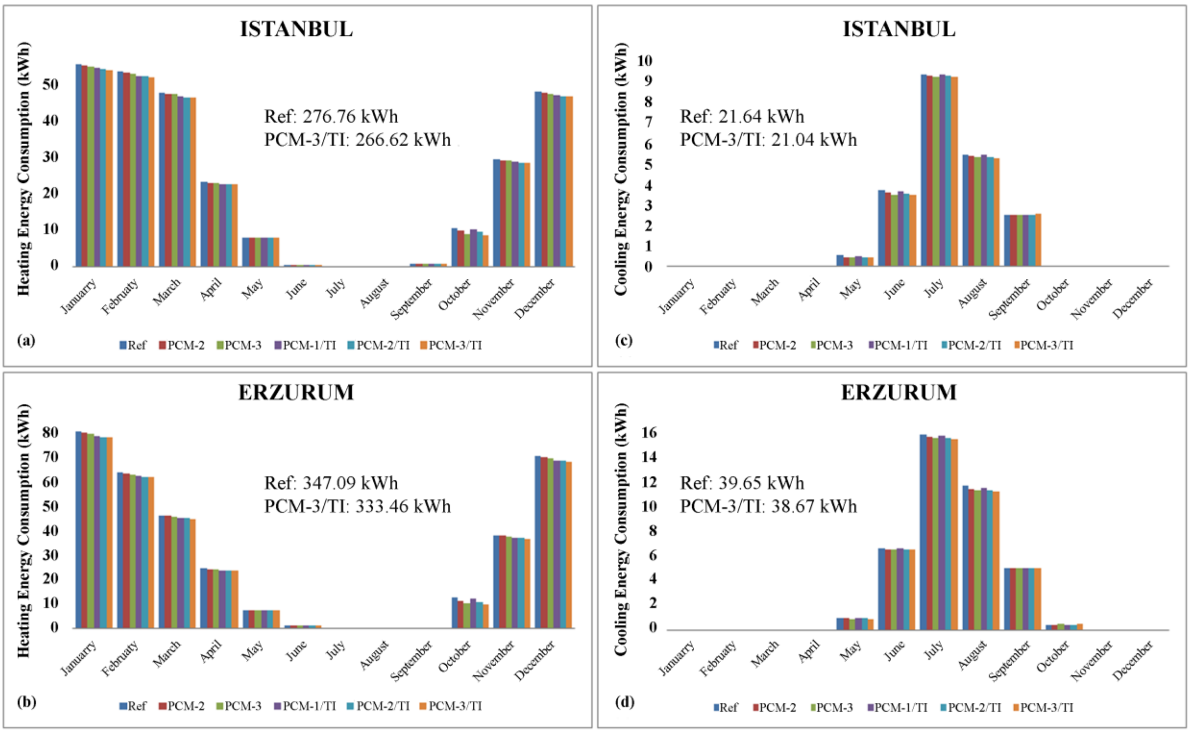

Fig. 5. The reference, total heating and cooling energy consumption of buildings with PCM and PCM-TI integrated walls: (a) Istanbul (Heating); (b) Erzurum (Heating); (c) Istanbul (Cooling); (d) Erzurum (Cooling)

In Istanbul, during the winter period, the annual total heating energy consumption of the reference building is 276.76 kWh. With the PCM-3 wall section, this consumption decreases to 271.81 kWh, and with the integration of PCM-3/TI, it further decreases to 266.62 kWh. In Erzurum, the annual total heating energy consumption of the reference building is 347.09 kWh. The use of PCM-3 in the wall section reduces this to 340.44 kWh. With the integration of TI in this wall section, the annual total heating energy consumption is determined to be 333.46 kWh. Based on these findings, it can be stated that integrating multiple-layered PCM and TI together in the wall sections yields positive results in terms of heating energy savings during the winter period (Fig. 5a, Fig. 5b).

According to Fig. (5c and 5d), in Istanbul, during the summer period, the annual total cooling energy consumption of the reference building is 21.64 kWh. With the integration of PCM-3, this energy consumption decreases to 21.13 kWh. With the integration of TI in this wall section, the annual total cooling energy consumption is determined to be 21.04 kWh. In Erzurum, a cold climate region, the annual total cooling energy requirement is 39.65 kWh, reduced to 38.89 and 38.67 kWh with the use of PCM-3 and PCM-3/TI, respectively. A higher annual total cooling energy consumption is calculated in Erzurum, compared to Istanbul. This indicates that the average air temperature of the region is not the only significant parameter affecting heating and cooling energy consumption in buildings. Typically, global solar radiation intensity increases as the altitude of a region rises (Qu et al., 2021). The solar radiation intensity for the representative cities is obtained from the Türkiye Solar Potential Atlas prepared by the Turkish Meteorological Service (Türkiye Güneşlenme Potansiyeli Atlası, 2010). Table 5 shows that solar radiation intensity increases gradually with altitude in Istanbul and Erzurum. The altitudes of Istanbul and Erzurum are 40 m and 1890 m, respectively. Due to the higher altitude in Erzurum, greater solar radiation intensity results in more heating of the building envelope during midday, thus allowing the PCM to store more energy and increasing the cooling load. The solar radiation intensities in Istanbul and Erzurum are 1389 KWh/m² and 1493 KWh/m², respectively. Therefore, the total cooling energy consumption for the building may be higher. It can be concluded that when designing passive buildings using PCM technology, it is important not to rely solely on climate classification, but also to consider other geographical factors such as altitude and solar radiation intensity.

During the winter period, the highest energy savings were achieved in the wall section, containing three-layered PCM in the inner region and TI in the outer region, with the (PCM-3/TI) having values of 3.66% in Istanbul and 3.93% in Erzurum. Similarly, during the summer period, the highest energy savings were also obtained with the PCM-3/TI wall section, achieving 2.77% in Istanbul and 2.47% in Erzurum. Based on all these findings, it has been determined that the combined use of three-layered PCM in the inner region and TI in the outer region offers advantages. These advantages include annual heating and cooling energy savings compared to the reference building with single-layered PCM.

3.3. Economic Findings

Fig. 6 shows the calculated values of the key economic parameters such as ECS and PP in determining the economic effectiveness of building envelopes with PCM and PCM-TI combinations.

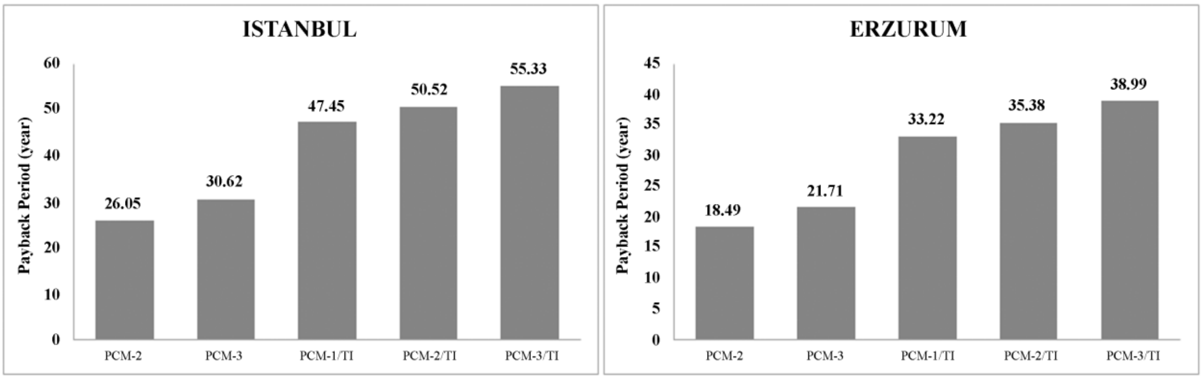

Fig. 6. Payback periods according to climate zones

Istanbul's temperate humid climate conditions result in buildings being exposed to both heating and cooling loads (İl ve İlçeler İstatistikleri, 2024). Therefore, the use of PCM-TI combinations to enhance the energy efficiency of the building envelope is of great importance. When only multiple-layered PCM is used in Istanbul (PCM-2, PCM-3), the PP is determined as 26.05 years and 30.62 years, respectively. Even without TI integrated, these relatively long PP are primarily due to the temperate and humid climate characteristics of Istanbul, which limit the thermal effectiveness of PCM, and the cost of the materials used in the building envelope, which extends the PP relative to the energy savings achieved. The use of PCM-TI further increases the PP. The PCM-3/TI combination, which provides the best thermal performance for both the heating and cooling seasons, results in a PP of 55.33 years.

Erzurum, located in the fifth-degree climate zone, is one of the coldest cities in Türkiye; and the long and snowy winter months significantly increase the heating demand (İl ve İlçeler İstatistikleri, 2024). In buildings with wall sections containing only multiple-layered PCM (PCM-2, PCM-3), the PP are calculated as 18.49 years and 21.71 years, respectively. The PCM-3/TI combination, which provides optimal thermal performance for both the heating and cooling seasons, results in a PP of 38.99 years.

The effect of the increase in the number of PCM layers on the PP results in a rise in investment costs, and limited savings beyond a certain point. The longer PP for PCM-3 compared to PCM-2 in both climate zones indicates that the contribution of each additional layer to thermal performance continues to diminish, and an optimal cost-effectiveness limit can be reached.

Moreover, while the use of PCM in conjunction with TI improves thermal performance in both Istanbul and Erzurum, it further extends the PP. The calculated PP of 55.33 years (Istanbul) and 38.99 years (Erzurum) for the PCM-3/TI combination highlights the need for careful optimization of integrated solutions in terms of cost-effectiveness. Consequently, the increase in the number of PCM layers contributes to energy performance, although it requires a cost-benefit balance at different scales for each climate zone. As is well known, according to the Turkish Building Earthquake Regulation (2018), the economic lifespan of buildings is generally considered to be 50 years (Türkiye Bina Deprem Yönetmeliği, 2018). Since the PP obtained in this study is calculated as less than 50 years for all the scenarios examined, the combined use of PCM-TI in the same wall section can be considered an economically viable solution. The PP values for the PCM-3/TI combination, which provides the best thermal performance for both heating and cooling periods, are 55.33 years for Istanbul and 38.99 years for Erzurum. While the result for Istanbul is on the borderline in terms of economic sustainability when compared to the building's lifespan, it is evident that this integration is more advantageous in colder climate regions such as Erzurum.

4. Conclusions

The possibilities of using multiple-layered PCM to improve the thermal performance of an educational building and reduce annual heating and cooling energy consumption have been investigated. The results obtained from the studies conducted within this scope are as follows:

- In wall sections where both PCM and TI are used, not only climate classification but also other geographical factors such as altitude and solar radiation intensity should be considered. Although the average air temperatures in Erzurum are lower than in Istanbul, the solar radiation intensity is higher due to the city's higher altitude. This results in an increased heat gain in the building envelope during midday hours, leading to higher cooling energy consumption.
- During the winter period, using a wall envelope with three-layered 30 mm PCM (with a melting temperature of 21 ºC) on the interior and 30 mm TI on the exterior results in energy savings during the summer period, using three-layered 30 mm PCM (with a melting temperature of 27 ºC) on the interior and 30 mm TI on the exterior (PCM-3/TI) results in energy savings of 2.47-3.93% compared to the use of single-layered PCM (Ref).
- The combinations of PCM-TI, as well as the increase in the number of PCM layers, are the primary factors that increase the PP. However, considering the high thermal comfort provided by the combination of multiple-layered PCM and TI for both heating and cooling periods; along with the reduced ITR throughout the day; and higher total heating and cooling energy savings, the use of this combination is beneficial.
- The PP values obtained by increasing the number of PCM layers being shorter than the typical building economic lifespan of 50 years, demonstrate that the combination of multiple-layered PCM and TI offers a viable and cost-effective solution. However, the calculation of the PP for the three-layered PCM and TI combination (PCM-3/TI) as 55.33 years in Istanbul indicates that this integration does not provide the same economic advantage for all climate regions. This situation arises from the temperate and humid climate conditions in Istanbul, which limit the thermal efficiency of PCM, and the cost of the materials used in the building envelope, which extends the PP comparison to the energy savings achieved. However, in Erzurum, the PP (18.49-38.99 years) being shorter than the building's economic lifespan suggests that increasing the number of PCM layers improves the ITR and enhances the thermal efficiency of the building envelope that by providing energy savings.

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The impact of plan configurations and design decisions in healthcare facilities on wind resilience of roofs

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Abstract. This study aims to evaluate how architectural design decisions affect wind-induced pressures and the material fragility of roof coverings. The analysis considers various plan configurations with different building aspect ratios. It aims to quantify the extent to which design models and stereotypical design approaches in healthcare facility design influence the fragility of roof coverings. For this purpose, three inpatient unit layouts—single corridor, racetrack, and compact square—were examined, each characterized by distinct building aspect ratios. These layouts were analyzed across six building height categories (low, medium, and high-rise), four roof types (flat, single slope, double slope, and hipped), and for roof types where slopes are available, roof slopes of 5°, 30°, and 60°, in alignment with EN1991-1 standards. The research reveals that architectural design decisions have a significant impact on wind-induced pressures, especially in critical roof zones. Hipped roofs with 30° slope gave the best pressure and fragility results, while flat roofs and those with 5° slope exhibited more fragility. It is evident that Terrain Category 0, most critical wind conditions, produces the maximum wind load, thus emphasizing the integral design requirement under such conditions. The present study offers a novel systematic method that binds a wide range of architectural parameters and performance metrics into a cohesive calculation framework. This methodology effectively links design decisions to wind-resilience outcomes and presents rapid calculation models to performance-based design principles. As a result, this study brings actionable insights for architects toward optimizing the design process for resilience and performance.

Keywords: Fragility assessment; Healthcare facility design; Performance-based design; Roof covering; Wind performance

1. Introduction

The set of architectural decisions such as layout characteristics, facade design, building geometry, roof type, context, corner modifications, and building orientation are considered as determinants for wind exposure (Davenport, 1971; Hoxey et al., 1993; Kwok, 1998; Merrick & Bitsuamlak, 2009; Nagar et al., 2020). In the case of healthcare facilities, wind pressures can have significant consequences, as these structures often have many windows, higher walls, and other features that can make them vulnerable to wind damage. The inefficient choice of geometries in design can lead to higher construction costs for buildings if the wind exposure is not considered carefully. Like most buildings, healthcare facilities are bluff body objects in wind dynamics studies. Air flowing around and over these bluff bodies usually creates turbulent wake zones behind them. One of the most sensitive elements in this context is the roof, often subject to significant uplift forces and pressure fluctuations. Understanding how design configurations affect wind-induced pressures is crucial to optimize building performance and reduce material fragility.

Wind-induced loading conditions present additional importance in healthcare facilities because these buildings must be able to bear up to extreme weather conditions and maintain their structural and operational integrity to ensure the safety of patients, staff, and visitors (Chand & Loosemore, 2015; Ceferino et al., 2020). This necessity underlines the need for additional considerations in the case of healthcare facilities. Additionally, healthcare facilities are obligated to meet additional regulations and they are subjected to more rigid rules. Design decisions made to meet these regulations and rules appear as phenomena that influence the shape of hospital morphology (Guerrero et al., 2022). Accordingly, these regulations, which cannot be ignored when making design decisions, should also be among the factors affecting morphology.

Within the context of this study, the term "morphology," refers to the overall mass of healthcare facilities. Therefore, the roof of the structure, which holds great importance in terms of wind pressures, is one of the leading research topics in this framework. In this manner, healthcare facilities present a unique opportunity wherethe

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design of inpatient floors are considered as critical in shaping the overall morphology of hospital buildings. Compared to other components such as emergency departments or outpatient clinics, inpatient units necessitate a lower level of connectivity to main entrances and exits. Therefore, they are more likely to be positioned at higher levels where wind forces are more effective. Thus, a thorough understanding of design decisions and their influence on the wind forces and chosen roof material is crucial.

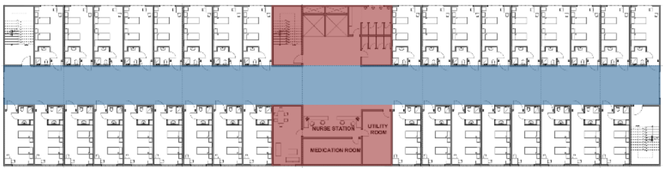
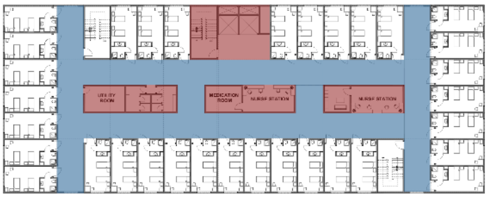
To achieve this objective, this study aims to examine the impact of design decisions in inpatient units on building zones vulnerable to wind forces, with a particular focus on roofs. Three frequently repeating layout types for inpatient units, namely single corridor, racetrack and compact square (Kobus et al., 2008) were identified for further investigation. Each type represents a different layout configuration within the inpatient care units which indicates a different behavioral setting. These hypothetical hospital floor types have provided basic analytical units to be studied in the calculations. Furthermore, the study employs the widely accepted wind calculation protocol, EN1991-1, and calculates wind pressure acting on different zones suggested by the same methodology. Therefore, 14.400 hypotectical scenarios were calculated considering various cases. To handle this process a Java code was created by the authors. The calculations and building matrix are explained in the method chapter in detail.

By simulating how different architectural configurations influence wind pressures, particularly on roof zones, this approach allows for a comprehensive analysis of how morphology-related design decisions affect the structural resilience and material fragility of healthcare facility roofs. Therefore, the central research question this study addresses is: How do architectural design decisions influence wind-induced pressures and the material fragility of roof coverings in healthcare facility inpatient units?

2. Methods

The main objective was to establish a basis for comparability and ensure that various plan types serve as representative models for typical inpatient floor layouts. To achieve this comparability, the structural axis spacing, room type, and auxiliary spaces were kept unchanged. These fixed features were integrated into these generic layouts while remaining faithful to their working principles. To obtain some of the data needed for calculating wind loads, additional data for these plan diagrams had to be provided. Although all these plan types - single corridor, racetrack, and compact square (Table 1) - are variations of the rectangular form, they propose different aspect ratios. Accordingly, the prominent phenomenon to be questioned here is the relationship of architectural decisions arising from the functioning schemes of these space examples with similar capacities with structural loads. The study considers the wind load and examines its relationship in more detail.

Table 1. Plan Schemes

Plan Type	Scheme
Single Corridor	
Racetrack	
Compact Square	

* Blue indicates circulation zones. Red denotes service areas, including nurse stations, support rooms, elevator lobbies, and main stairs, classified as service due to their role in staff circulation.

In order to calculate wind loads, the protocol necessitated additional data including window sizes, building dimensions, roof type, and certain environmental parameters. The generic plan types have been developed in detail to cover the necessary data for these floor types by using the repeating layout components (Table 2). Data such as environmental factors, building height, and roof type were obtained by making separate calculations for each possibility, providing the necessary details for these plan schemes. In order to track this multivariate process efficiently, a six-digit code system was developed also in order to express the characteristics of the buildings. Each digit was assigned with a changing variable and used these building definitions as descriptors to introduce these buildings to the Java program that has been created. Each hypothetical building has a unique code, which represents the characteristics of the building proposed by each letter. The code is designated as idjkpz, with the number corresponding to each digit. The key is as follows: i (floor plan type), d (building direction) j (building height), k (roof type), p (roof pitch) and z (exposure category). For example, building 1x52a1 indicates a 15-story, that has a mono pitched roof with 5° pitch and has a single corridor plan type with the x direction and is in the Terrain Category IV as specified by EN1991-1.

A series of calculations by varying the height factor to establish the level of influence the height factor has been conducted. These buildings were classified as low-rise, mid-rise, utand high-rise. Moreover, two examples from each category were implemented. Buildings with 3 and 4 floors are categorized as low-rise, buildings with 6 and 9 floors as mid-rise, and buildings with 15 and 20 floors as high-rise (Table 3). The roof types specified in the roof type table (Table 4) are specified as defined by EN1991-1. Each hipped roof type's calculations involve three scenarios with 5°, 30°, and 60° roof slopes. The *p* input in the building code is the letters: "*a"* for 5°, *"b"* for 30°, and *"c"* for 60°. The building codes have no *p* input for the flat roof type. For the hypothetical calculations with flat roof type, it is assumed that these buildings have parapet walls with a height of 0.025 of the building height. As environmental conditions 5 terrain categories were employed. The *z* input in the building code implies these terrain categories where 1 is "Terrain Category 0", 2 is "Terrain Category I", 3 is "Terrain Category II", 4 is "Terrain Category III", 5 is "Terrain Category IV".

Table 2. Plan Type Specifications

Geometry Code (I)	Inpatient Unit Layout Type	Number of Patients	Aspect Ratio	Area (m²)	Number of NS	Area-patient ratio
(I=1)	Single Corridor	72 (36*2)	4,09	1.805	1	25
(I=2)	Racetrack	66 (33*2)	2,56	1.941	2	30
(I=3)	Compact Square	56 (28*2)	1,00	1.537	1	27

Table 3. Building Height Codes

Height Code (J)	**Floor Number**
(J=1)	3
(J=2)	4
(J=3)	6
(J=4)	9
(J=5)	15
(J=6)	20

Table 4. Roof Type Codes

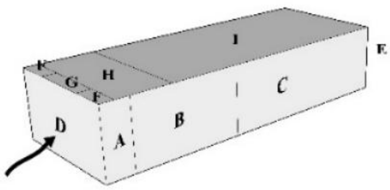
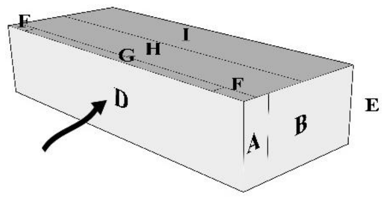
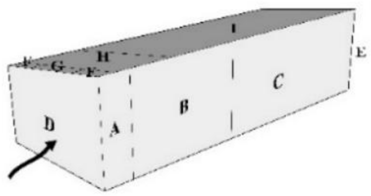
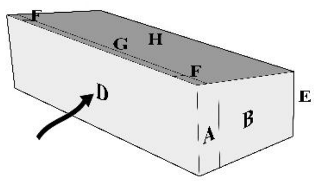
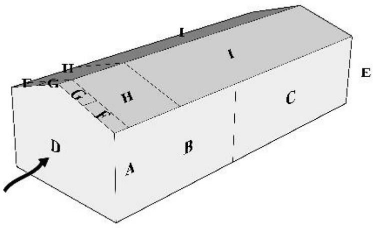
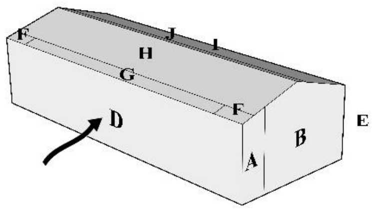
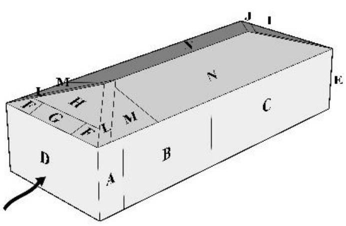
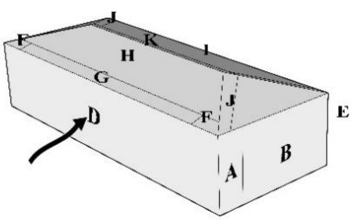
Roof Code (K)	**Roof Type**
(K=1)	Flat Roof
(K=2)	Monopitch Roof
(K=3)	Duopitch Roof
(K=4)	Hipped Roof

In summary, the study aims to address the need of comprehensive investigation of the effects of design decisions. These decisions, which are interdisciplinary in nature, determines the extend of wind forces and material responses. Thus the study illustrates the mentioned effects through hypothetical cases. It employes the commonly used EN1991-1 as calculation method and uses its environment and roof definitions as building morphology alternatives. By standardizing key layout components while varying critical parameters such as height, roof configuration, orientation and environmental exposure, the study ensures comparability between different design scenarios. The use of a structured coding system facilitates efficient data tracking and simulation in the Java-based computational tool, enabling high-volume, detailed analysis on 14,400 hypothetical cases. This robust approach paves the way for meaningful insights into the interaction between hospital morphology and structural vulnerability to wind forces, thus providing valuable guidance to the design of resilient healthcare infrastructure. The study also emphasizes the need for interdisciplinary approaches in designing complex buildings such as hospitals.

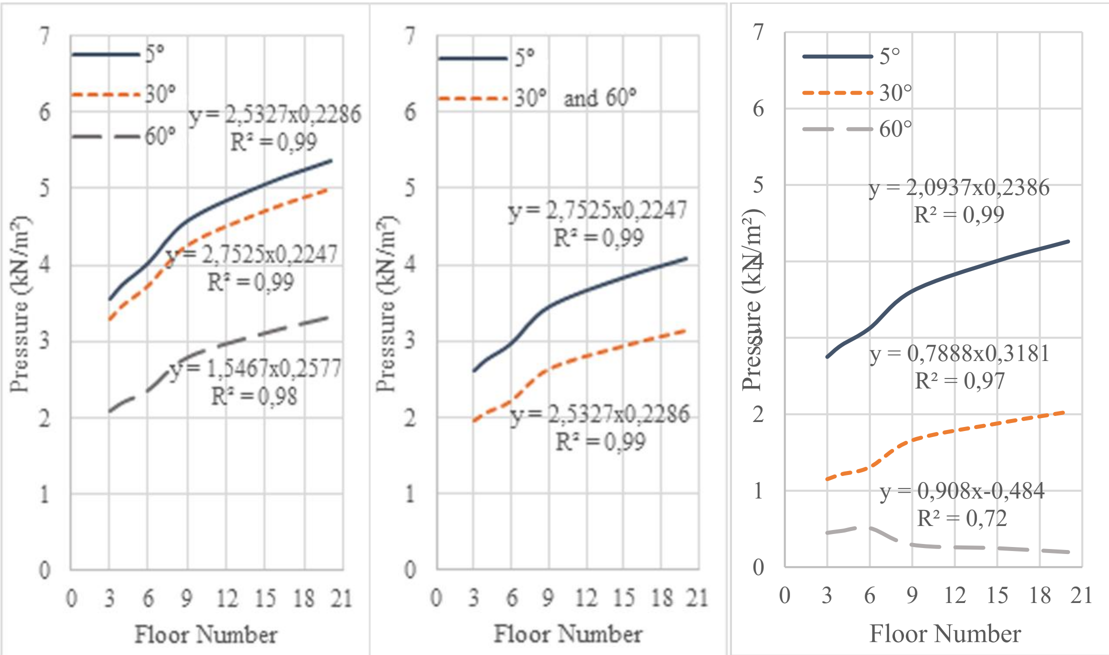
3. Results and Discussion

Within EN1991-1, many roof types, namely flat, mono-pitched, duo-pitched, hipped, and multi-span, have been examined. Accordingly, four widely used types of roofs were included in the analysis; flat, mono-pitched, mono-pitched, duo-pitched, and hipped roofs (Table 5). In EN1991-1 depending on the types of these roof types, different zoning is used, and different coefficients are given for different roof slopes. Furthermore, the most critical and excessive loads on the roof occur at the corners on the side of the wind, defined as the F zone by EN1991-1. Accordingly, the F zone, which is typical for each roof type and has a critical value, is analyzed. The forces that occur in this region are generally suction forces. Therefore, the analysis of these zones and the wind forces is essential for the roof covering and joint detail choices (Lee et al., 2013).

Table 5. Roof types and loading directions

Roof Type	Direction x	Direction y
Flat Roof		
Monopitched Roof		
Duopitched Roof		
Hipped Roof		

Variation of wind velocity pressure against number of floors is shown in Fig. 1. As illustrated in Fig. 1, the hipped roof configuration consistently results in the most favorable, lowest, pressure values among the various roof types examined. The information presented in Fig. 1 pertains to Building Type 1x (Single corridor), characterized by a lateral dimension of 86×21 meters. Furthermore, the dataset presupposes that the structure is located in an area categorized as Terrain Category 0, encompassing maximum wind pressure values. It is imperative to highlight that within the scope of the investigation focusing on various roof types and inclinations pertinent to the specified region, it was determined that exclusively the hipped roof variant, identified as 4c, exhibiting a slope of 60 degrees, yielded positive pressure values. In addition, the same values were obtained for the building types, with the height and aspect values determined for the roof types with 30 and 60-degree slopes for the roof model 3 (duopitched roof), which were defined as duo pitched by EN1991-1.



a) b) c)

Fig. 1. Number of floors vs. peak wind velocity pressure at Zone F for a) mono pitched roof b) duo pitched roof c) hipped roof

More information on the behavior of roof type 2c (double pitched roofs with 60° slope) is shown in Fig. 2. These graphs show how the wind pressure changes along the number of storeys for different exposure directions. The graph on the left (1x, 2x, 3x) shows the pressure values when the wind approaches from the x direction of the building, while the graph on the right (1y, 2y, 3y) represents the y direction. Pressure increases with height in all exposure scenarios, albeit at different rates. In particular, exposure in the y-direction generally yields higher pressure coefficients, with the 2y curve reaching the highest peak pressure (~4.6 kN/m²). This is due to the fact that in the plan types provided, the side of the y-type perpendicularly affected by the wind corresponds to the long side of the rectangular shape. The most conservative scenario, 2y, should be considered critical in structural design as it emphasizes the sensitivity of steeply pitched double-pitched roofs to high wind forces, especially from certain directions. This behavior reinforces the importance of analyzing the directional wind effect and slope interaction when applying vulnerability assessments for roof design.

Moreover, damage to the building envelope can lead to adverse events later on when these areas are exposed to wind pressures or water-borne damage due to the loss of integrity of the building elements (Boughton et al., 2011). In this sense, fragility analyses were conducted to assess more deeply the implications of this review for the architect as design inputs. Fragility is defined as the probability of exceeding a specific state of damage (Abdelhady et al., 2022). Therefore, fragility curves are tools used to assess the risk of exceeding a certain damage or a limit. These fragility curves are used to determine the probability of exceeding limit values set by different parameters. They can be used as auxiliary tools in the design phase. One of the steps required for this assessment is to determine the limits that will be examined for the probability of exceedance, which are referred to as damage states. Accordingly, fragility curves can determine damage probabilities at the level of individual elements (Gavanski et al., 2014) and within a broader systemic framework (Dong & Li, 2016).

In this study, fragility curves were developed to understand the link between roof selection and damage probability. In this context, analyses for each roof type were used. These analyses were performed for the F zone, which is subjected to the highest pressures. Since the main purpose of the brittleness analysis is to understand the effect of roof morphology, the analysis is based on the fracture limit of a single material. The sandwich panel was chosen as the material for the roof covering, and the fragility analysis of this specific material is detailed in Fig. 3-4. The breaking point of this material was taken as 3.25 kPa (Abdelhady et al., 2022) and analyzed separately for each roof type and slope. In light of the results, as seen in Fig. 3-4, it is observed that in cases where the roof slope is 5 degrees, regardless of the roof type, the material fragility exhibits similar vulnerabilities to the flat roof. The structures featuring hipped roofs exhibit minimal material fragility. Furthermore, within the range of slopes assessed, it was determined that roofs possessing a 30-degree incline demonstrated the most reduced fragility indices. Since the wind pressure coefficients of the roof types Monopitch and Duopitch in two different directions are highly different, only the data in the critical direction is used for the fragility analysis.

The calculation of roof loads within EN1991-1 follows a similar method to the calculation of wind loads acting on facades. According to this method, the calculated wind pressure value is multiplied by coefficients provided by the code. When these coefficients are analyzed, in most cases, the most critical loading occurs at the corners (zone F) (Alrawashdeh & Stathopoulos, 2015). However, in duopitched roof, at a slope of 30 degrees, the pressure at Zone G is higher than at Zone F. Furthermore, for pressures at Zone F in duopitched roofs and hipped roofs "wind forces in this region changes rapidly between positive and negative values on the windward face at pitch angle of +5° to +45°" as stated in EN1991-1. Therefore, for this region, in some cases, both negative and positive pressure coefficients provided by EN1991-1.

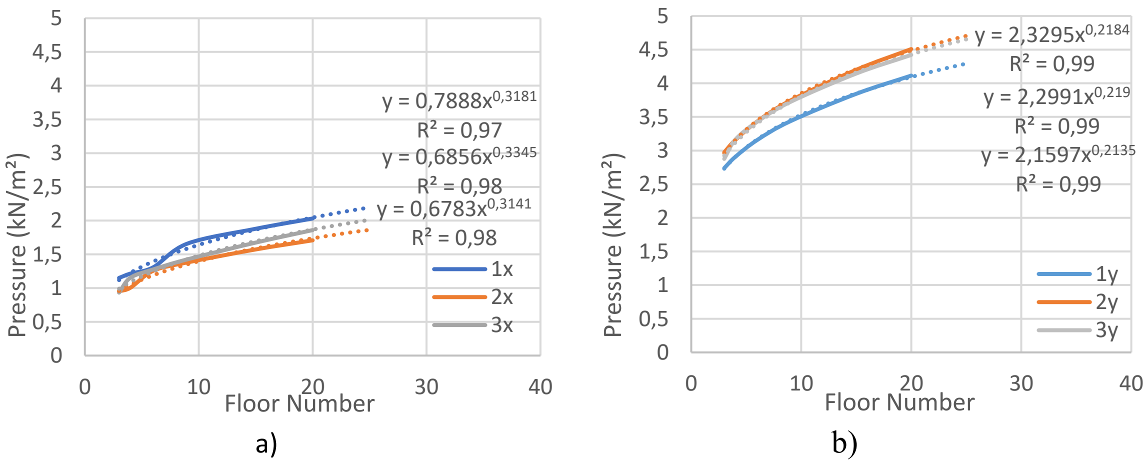


Fig. 2. Plan type analyses for duopitched roof with 60º slope (2c) a) direction x b) direction y

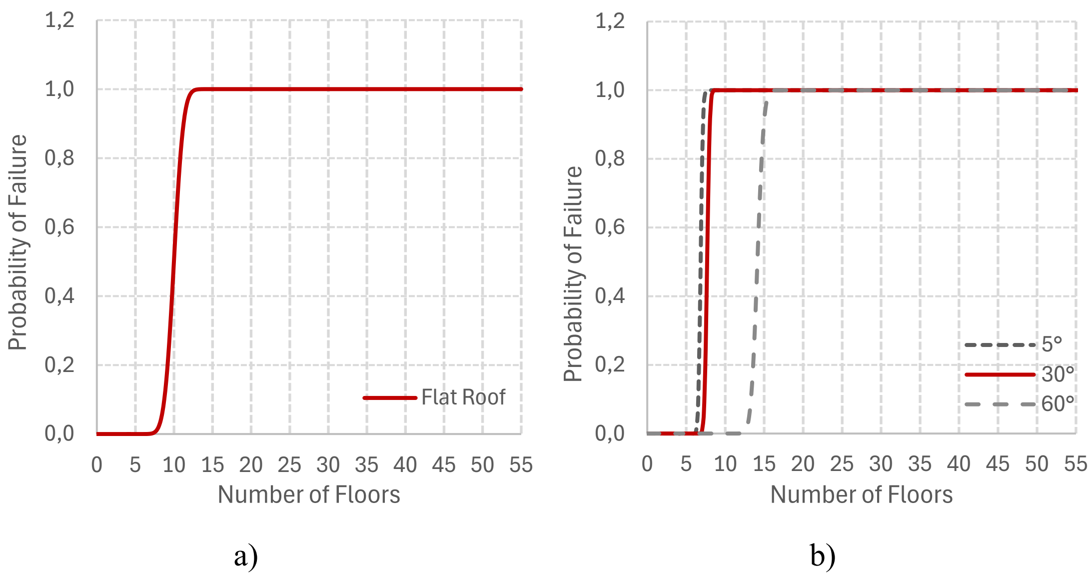
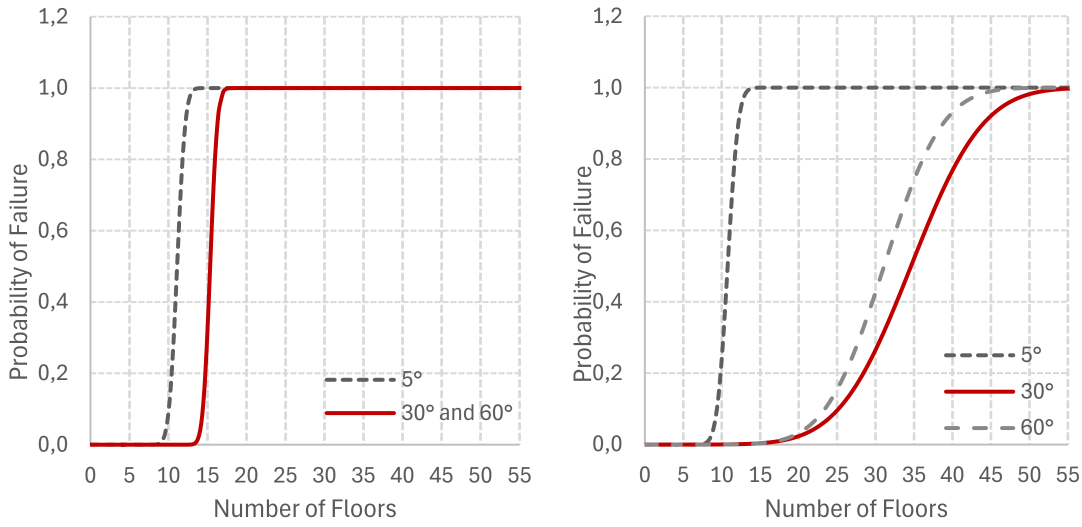


Fig. 3. Roof fragility curves a) Flat roof, b) Monopitch roof



c) d)

Fig. 3. Roof fragility curves c) Duopitch roof, d) Hipped roof

Based on the analysis conducted within the framework of this study, it was determined that among the various roof configurations evaluated, the monopitched roof configuration exhibited the highest-pressure values across all the slopes analyzed. In the fragility analysis, when the F region is examined in terms of material failure, it is seen that roofs with 5° slope exhibit similar material behavior to flat roofs regardless of roof type. A key finding from the analysis is that the pressure coefficients for roofs, as outlined in EN1991-1, display higher values for roofs with a 5° slope in comparison to those with different slopes. This distinction highlights the critical need to factor in slope variations when conducting structural analysis and design of roofing systems to guarantee their stability under diverse environmental loads.

Furthermore, our fragility analysis revealed notable differences in how monopitched and duopitched roofs respond to wind forces coming from two directions. Specifically, for monopitched roofs, the wind impacting perpendicularly to the higher side of the roof results in elevated pressure values in Zone F. Conversely, when the wind impacts the lower side, the pressure decreases. It's important to note that during the evaluation of these pressure values, the selection of materials was based on the most severe loading conditions encountered.

Consequently, the highest-pressure values were incorporated into the fragility analysis. As a result, when constructing the fragility curves for both monopitch and duopitch roofs, the analysis focused on wind load data impacting the structure from a singular orientation. On the other hand, for hipped and flat roofs, the analysis accounted for both orientations due to their similar response patterns to wind forces from any direction. This approach revealed that, for hipped roofs, the same materials require a significantly greater building height to reach failure, highlighting the importance of considering roof type and orientation in structural design and analysis.

4. Conclusions

This study investigated the influence of architectural design decisions—roof type, slope, and building height—on wind-induced pressures and the resulting material fragility in the roof of inpatient blocks within healthcare falcilities. Through a comprehensive simulation of 14,400 hypothetical scenarios based on EN1991-1 standards, the results highlight the structural implications of design morphology under extreme environmental conditions. The following conclusions can be drawn from the analyses.

- Roofs with a 5° slope exhibit behaviorsimilar to flat roofs under wind pressure, resulting in higher fragility levels compared to steeper slopes.
- Monopitch roofs are the most vulnerable, in the direction where they don't present slope, consistently generating the highest wind pressure values across all slopes, making them the least favorable option from a structural and economic standpoint.
- Hipped roofs offer superior resilience, requiring substantially greater building heights to reach failure thresholds, especially under Zone F pressures.
- 30° slopes emerged as the most efficient configuration, showing the lowest probability of material failure and the most favorable performance under wind loading.

These findings underscore the necessity of integrating wind-performance criteria early in the architectural design process. In healthcare settings—where structural robustness directly impacts operational continuity—designers must consider the relationship between roof configuration and wind-induced fragility to create safer, more resilient buildings.

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Evaluation of the effects of building form on the wind performance of structures

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Abstract.The increased use of fossil fuels has led to the depletion of these resources, environmental issues, and concerns over energy security, which have forced countries to turn to renewable energy sources. Many countries are accelerating this transition by increasing investments in renewable energy, with infrastructures like solar panels and wind turbines. With the advancement of turbine technology, integrated micro-turbines in buildings have become a subject of great interest in international literature today.
This study will conduct a literature review and evaluation of building configurations for the integration of wind turbines in order to improve the wind energy performance of the turbines. In the context of the relationship between wind turbines and building form, the effects of factors such as building height, aspect ratio, floor plan, and distance between buildings on wind speed and wind direction will be investigated. Since building form is a crucial design criterion that significantly affects electricity generation in wind turbine integration, an analysis focusing on building configurations for micro wind turbine integration will be conducted.
The data obtained from the evaluation will be used to create a design guide for generating wind energy through building configurations with wind turbine integration. It is believed that the results of this study will contribute to the successful and sustainable implementation of such projects, representing an important step toward the emergence of energy-independent buildings.

Keywords: Energy Production, Wind Turbine, Sustainable Buildings, Wind Flow, Building Form.

1. Introduction:

The use of fossil fuels significantly contributes to environmental pollution and carbon emissions, exacerbating global warming. In contrast, renewable energy, particularly wind energy, presents a promising solution to both the energy crisis and global warming. Buildings, as major consumers of energy, play a pivotal role in global warming. In 2019, buildings accounted for 35% of global energy consumption and 38% of global carbon emissions. To address rising energy demands, it is essential to prioritize renewable energy sources.

In Turkey, rapid urbanization has led to increased energy consumption, largely dependent on fossil fuels, thereby intensifying environmental pollution. Renewable energy, particularly wind energy, is viewed as a viable solution to mitigate these challenges. This research investigates the potential of buildings to generate energy from wind, aligning with the United Nations Sustainable Development Goals (SDGs), including affordable and clean energy, sustainable cities and communities, and climate action.

As part of its sustainability efforts, Turkey has introduced regulations mandating Net Zero Energy Buildings (NZEBs) to generate at least 10% of their energy needs from renewable sources starting in 2023 (The Ministry of Environment, Urbanization, and Climate Change introduced new provisions in the Official Gazette No. 31755). These regulations aim to promote energy-efficient buildings and sustainable construction practices.

The potential for increasing electricity generation through wind energy is considerable, particularly in areas with high wind energy potential. In regions such as the Aegean and Marmara, wind turbines are already deployed in wind farms independent of buildings. These farms, typically situated in rural areas, produce energy using turbines separate from buildings. However, given that wind energy potential increases at higher altitudes, integrating wind turbines into densely built urban areas could significantly enhance energy production, benefiting both the economy and environmental health of the country.

In urban settings, decentralized energy production using various renewable sources has the potential to meet part of the growing energy demand, helping address energy crises and mitigate climate change (Ayhan & Sağlam, 2012). In response to these needs, literature studies have examined wind flow analyses, building forms, and

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configurations within urban environments, with various trials and calculations conducted. Identifying optimal locations within and around buildings to efficiently harness wind energy is a critical step in integrating wind turbines into buildings.

Ilgın and Günel (2021) proposed a typological classification for wind energy integration in existing and planned buildings, presenting comprehensive and consistent strategies for architectural integration. Furthermore, Ilgın and Günel (2021), highlight the growing trend of incorporating wind energy into building designs, especially in high-rise structures globally. Their research suggests that in the near future, architects will design buildings capable of generating sufficient energy to meet urban energy needs, with wind turbines becoming an integral part of every building, particularly in high-rise contexts. They argue that interdisciplinary collaboration between architects and engineers is essential to combine renewable energy use, building function, and architectural design processes to foster innovative solutions. Ilgın and Günel (2021) also note a lack of research on the relationship between building form and wind energy utilization, particularly regarding the application of advanced micro turbines in new buildings in Turkey. This research seeks to fill this gap by developing a design approach for integrating micro turbines into building forms, facilitating the application of NZEB principles in new constructions.

Micro wind turbines, which are smaller and more suitable for residential areas, offer a feasible alternative to large-scale turbines, minimizing noise and light pollution. Previous studies have identified key design factors such as environmental conditions, building structure, and turbine specifications that can optimize energy production in wind turbine-integrated buildings.

In areas with wind potential, buildings can be integrated with micro turbines, enabling them to generate the energy they consume from wind. This approach will reduce dependence on fossil fuels. Traditionally, turbines have been installed in rural areas; however, thanks to technological advancements, they can now be mounted on buildings, thus optimizing energy production and addressing issues such as energy storage in recent studies.

In this study, a literature review will be conducted to examine the effects of building form on wind performance, and changes in building form that increase wind potential will be analyzed to determine building form alternatives. Thus, the integration of micro turbines can be optimized, maximizing the amount of energy produced. This research envisions a future where buildings become primary sources of energy.

2. Methodology

The primary objective of this study is to integrate micro wind turbines into buildings and enhance the existing wind energy potential through optimized building design, aiming to generate more energy than the building consumes. By establishing a relationship between the integration of micro wind turbines and building form, the goal is to achieve efficient energy production by optimizing the building's design. As an initial step, the research envisions buildings as primary sources of energy.

To achieve this, a comprehensive literature review will be conducted to examine existing studies on turbine integration into buildings and the impact of building forms on enhancing wind potential. From the review, design criteria will be identified, particularly focusing on how different building forms influence wind speed, wind direction, and subsequently, the efficiency of electricity production through wind turbine integration.

The data derived from the literature will be evaluated to identify key variables that improve wind performance in the context of building design. Specific building forms will be analyzed to determine their potential to optimize wind energy production. The findings will be used to propose formal design strategies for buildings capable of generating energy through wind energy, marking the first step towards creating self-sufficient, energy-generating buildings. The workflow of the study is illustrated in Fig. 1.

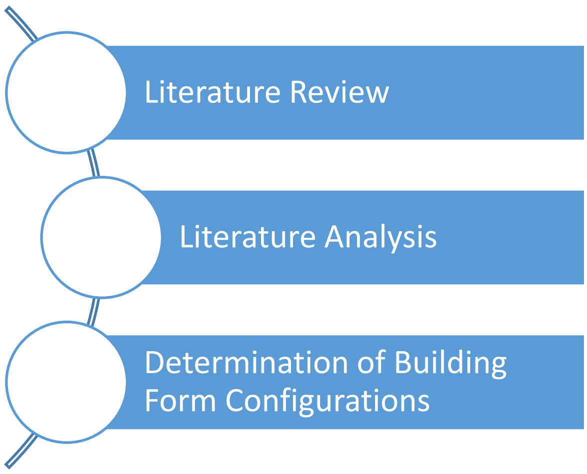

Fig. 1. Workflow of the study

3. Findings:
In accordance with the steps outlined in the "Methodology" section, the findings are presented under three distinct subheadings.

3.1 Literature Review
The foundational use of wind turbines in tall buildings is rooted in early wind analyses aimed at reducing structural vibrations in high-rise building designs. Initially, wind analyses focused primarily on designing building shapes that minimized structural vibrations. As turbine technology advanced, the integration of turbines into buildings became more common, and the potential for turbines to enhance wind energy production in tall buildings gained increasing significance. The first buildings to incorporate wind turbines for renewable energy generation were tall structures. This shift led to studies that not only explored the relationship between wind analyses and building form but also sought to optimize energy production through turbine integration.

The evolution of wind turbine technology, coupled with the rising demand for sustainable energy due to global population growth, has contributed to the widespread adoption of turbines. This trend supports their use at both urban and building scales, particularly in cities where energy consumption continues to rise. In urban environments, decentralized energy production—leveraging a variety of energy sources—holds the potential to meet a portion of the increasing energy demand while addressing energy crises and mitigating climate change (Ayhan & Sağlam, 2012). In response to these challenges, a body of literature has focused on wind flow analyses, building forms, and configurations within urban fabrics, examining the suitability of various locations within and around buildings to harness wind energy efficiently.

The height of the building is a key criterion in many of these studies. For example, Al Quran (2016) analyzed two different building heights, comparing them to the average surrounding height in various neighborhoods of Montreal. Balduzzi et al. (2012) adopted an average building height of 13.6 meters in their study of London's urban environment. Similarly, Shiraz et al. (2020) analyzed various alternatives in Montreal, considering the average height of buildings in selected neighborhoods. In areas where the tallest building stood at 44 meters, they opted for a 30-meter structure, while in a neighborhood with a 200-meter tall building, they selected a 140-meter building. Furthermore, Lu and Sun (2014) conducted computational fluid dynamics (CFD) simulations to explore the feasibility of using wind energy in Hong Kong's high-rise buildings, concluding that the substantial building heights and their clustering effects made wind energy usage theoretically promising.

Wang et al. (2015) investigated the impact of various aspect ratios and building heights on wind speed and wind energy density. Their study found that buildings with smaller plan areas—those with shorter lengths or narrower widths—generally had higher wind energy densities compared to larger buildings. However, they cautioned that the total amount of energy produced and the economic feasibility should also be considered in practical applications.(Fig. 2.)

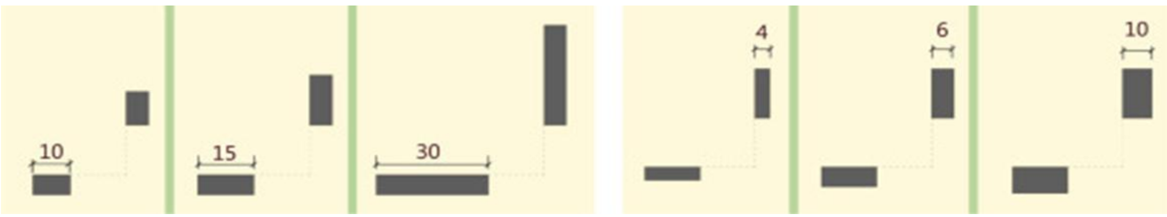

Fig. 2. Building Ratio (Wang et al, 2015)

Building corner modifications have been found to significantly enhance the aerodynamic performance of tall structures. Zhou et al. (2017) conducted CFD simulations to assess wind flow around low-rise buildings with different geometries to identify the optimal building form. Their study, which considered four building shapes—cuboid diffuser, cylinder diffuser, semi-cylinder diffuser, and composite prism diffuser—demonstrated that the composite prism diffuser, characterized by a rectangular prism with chamfered edges, outperformed the other shapes by maintaining more stable wind speeds across various heights. The study further optimized the building's geometry, determining that the ideal aspect ratio was 10x4, with a chamfer radius of 0.6 meters yielding the best results in terms of wind speed.(Fig.3)

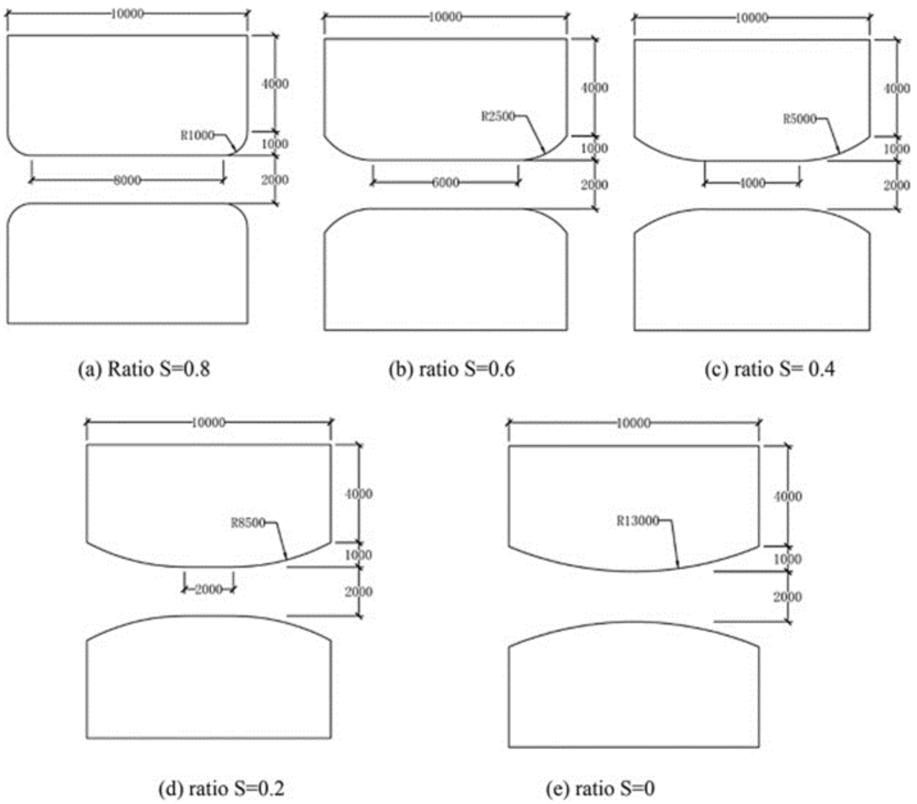

Fig.3. Building Corner Modifications (Zhou, 2017)

Similarly, Kono and Kogaki (2012) used Large Eddy Simulation (LES) to analyze wind flow around a rectangular, isolated prism-shaped building. Their findings revealed that wind power density was higher at the upper edge of the roof, influenced by wind direction, and that the velocity profile exhibited less variation. In another LES study, they examined the effects of wind direction and horizontal aspect ratio on the wind flow pattern of high-rise cuboid buildings.

Numerous studies have confirmed that corner modifications can reduce wind resistance and the wind-induced response in wind-resistant tall buildings (Xie, 2014; Thordal et al., 2020; Gu and Quan, 2004). The effects of different corner shapes—such as chamfered, recessed, fluted, and rounded corners—on wind pressure distribution across building surfaces have been extensively investigated through wind tunnel experiments (Li et al., 2018; Kawai, 1998; Kwok, 1988; Tamura and Miyagi, 1999; Carassale et al., 2014) and computational fluid dynamics (CFD) simulations (Thordal et al., 2020; Elshaer et al., 2016, 2017; Tamura et al., 1998; Bernardini et al., 2015; Alminhana et al., 2018; Juan et al., 2021c).(Fig 4.)

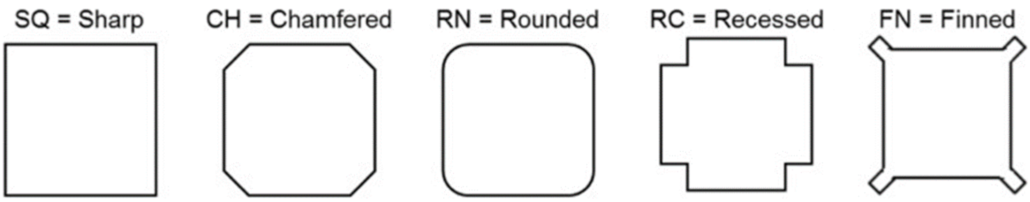

Fig.4. Different Corner Shapes for Buildings (Juan, 2024).

In a more recent study, Juan et al. (2024) conducted CFD analyses on various corner configurations, emphasizing the importance of incorporating aerodynamic principles into early-stage building design to optimize wind energy performance. They found that rounded corners can increase power density while reducing turbulence, thus improving the performance of rooftop turbines. Moreover, longer chamfer lengths and larger corner radii further enhanced wind flow, supporting more efficient energy generation. The study also highlighted the potential for vertical-axis wind turbines (VAWTs) to be strategically placed in the corridors between buildings with rounded edges, presenting new opportunities for wind energy generation. This body of research underscores the importance of considering corner geometry and prevailing wind conditions in the design of sustainable and energy-efficient urban environments.

3.2 Literature Analysis

The increasing global population and growing demand for sustainable energy have accelerated the development and integration of wind turbine technologies at both urban and building scales (Ayhan & Sağlam, 2012). In urban environments, where energy consumption continues to rise, on-site decentralized energy production holds significant potential for mitigating the effects of energy crises and climate change. In this context, various studies have investigated the relationship between building form and wind flow characteristics, emphasizing the importance of considering aerodynamic behavior in the early stages of architectural design.

3.2.1 Building Height and Wind Energy Utilization

Since wind speed generally increases with altitude, building height is considered a critical parameter for the effective use of wind turbines. Several studies have evaluated wind energy potential by analyzing different building heights in various urban morphologies. For instance, Al Quran (2016) examined two different building heights across various neighborhoods in Montreal, using the average surrounding building height as a reference. Similarly, Shiraz et al. (2022) selected 30 m and 140 m buildings for their analyses in areas where the tallest buildings were 44 m and 200 m, respectively. Lu and Sun (2014), through CFD simulations conducted in Hong Kong, demonstrated that high-rise buildings possess significant potential for wind energy generation due to their elevation and the wind concentration effects caused by surrounding structures.

3.2.2 Plan Ratio and Energy Density

The geometry of the building footprint, particularly its plan ratio and base area, also plays a vital role in determining wind energy density. Wang et al. (2015) found that buildings with smaller plan areas (e.g., narrow or short facades) tend to exhibit higher wind energy density. However, they also emphasized that total energy output and economic feasibility must be considered alongside wind density in real-world applications.

3.2.3 Corner Modifications and Aerodynamic Performance

Corner design is a key factor in improving a building's aerodynamic performance, influencing both wind-induced loads and the efficiency of wind turbines. Zhou et al. (2017) conducted CFD simulations on four different low-rise building forms and identified the chamfered rectangular prism (composite prism diffuser) as the most effective shape for maintaining stable and enhanced wind speed. Their findings also showed that a chamfer radius of 0.6 meters yielded optimal wind conditions.

Similarly, studies by Kono and Kogaki (2012) using Large Eddy Simulations (LES) revealed that wind power density was highest along the upper roof edges, depending on wind direction, making these zones suitable for turbine placement. More recently, Juan et al. (2024) emphasized through CFD analyses that rounded corners help reduce turbulence while increasing power density, leading to improved rooftop turbine performance. The study also highlighted the potential of vertical-axis wind turbines (VAWTs) placed between rounded-edge buildings, offering new opportunities for efficient turbine integration.

3.2.4 Wind Direction and Urban Layout

The alignment of buildings with prevailing wind directions and their spatial configuration within the urban context also significantly influence wind energy performance. The Venturi effect, often occurring between closely spaced tall buildings, can increase wind speed and enhance turbine efficiency (Lu & Sun, 2014). Therefore, building form must be considered not only at the individual scale but also in relation to its environmental context.

Based on the findings of the literature review, several key factors influencing wind potential at the building scale have been identified. Building height plays a significant role in wind energy production, while the plan ratio (width-to-length) affects the density of energy capture. Additionally, corner modifications contribute to aerodynamic performance, enhancing or reducing airflow efficiency around the structure. Furthermore, the orientation and spatial positioning of buildings within urban settlements have been shown to influence local wind speeds, thereby affecting the overall effectiveness of wind energy systems integrated into the built environment (Fig. 5).

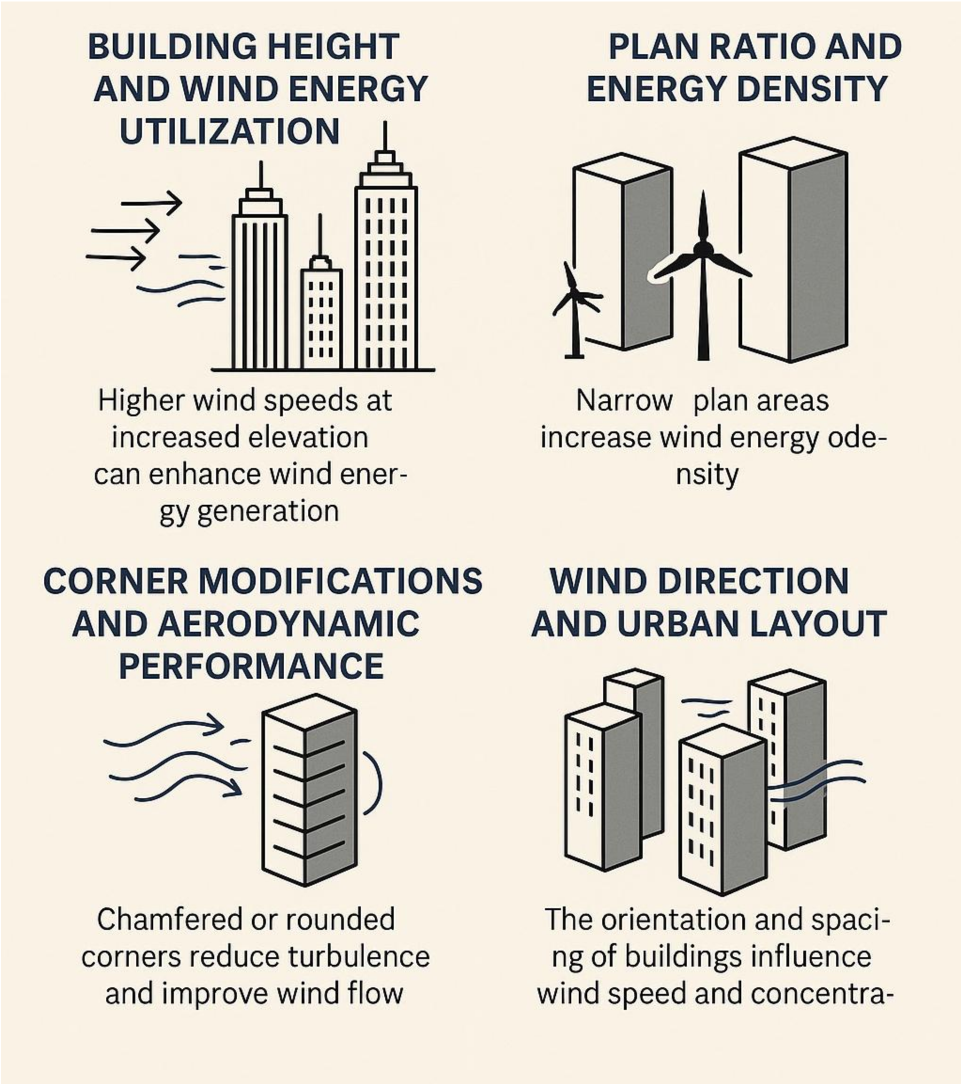

Fig.5. An Evaluation of the Impact of Building Form on Wind Potential: A Literature-Based Review

3.3. Determination of Building Form Configurations

In the literature-based study, the evaluation of the impact of building form on wind potential revealed that building height affects wind energy utilization, plan ratio influences energy density, corner modifications affect aerodynamic performance, and wind direction has an impact on urban settlements. Design decisions outside urban settlements are made at the building scale and influence architects' design choices. In the integration of microturbines, identifying the area on the building surface with the highest wind potential is important for increasing the amount of energy generated. Therefore, this study aims to identify building configurations that enhance wind potential in order to improve the energy performance of buildings utilizing wind energy. Based on previous research in the literature, alternative building forms have been proposed at the building scale by considering the form factors that influence wind potential, such as building plan aspect ratio (width/length), building height, and corner modifications (Fig. 6).

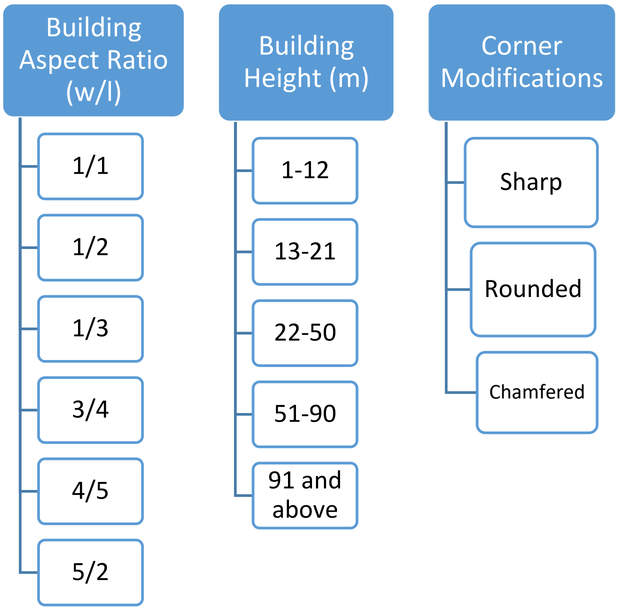

Fig.6. Form-Related Factors Affecting Wind Potential at the Building Scale and Alternative Building Configurations

4. Conclusions

This study has demonstrated that the integration of wind turbines into building designs, particularly when optimized, can significantly enhance energy production. The growing global emphasis on mitigating climate change and reducing carbon emissions underscores the increasing importance of renewable energy solutions, especially within urban environments. In this context, the incorporation of wind turbines into high-rise buildings represents a promising approach to addressing energy demands while minimizing environmental impacts.

The literature review and subsequent analysis reveal that several factors, including building height, shape, and wind flow dynamics, are critical in determining the efficiency of wind turbine integration. Taller buildings, in particular, benefit from stronger wind currents at higher altitudes, which are crucial for maximizing energy production. Additionally, modifications to building shapes—especially at the corners—can substantially improve wind speed and turbine performance. Chamfered and rounded corners, for example, reduce the area that is unsuitable for turbine placement, thus providing more available space for energy generation.

This research also highlights the potential of integrating micro wind turbines into buildings as a means of reducing reliance on fossil fuels and achieving Net-Zero Energy Buildings (NZEBs). Investigating the effects of building form on wind performance is essential for designing more energy-efficient and sustainable structures. Furthermore, the study underscores the importance of interdisciplinary collaboration, emphasizing that cooperation among engineers, architects, and renewable energy experts is essential to the successful development of integrated energy solutions.

In conclusion, the integration of wind turbines into buildings—especially through the use of micro turbines and optimized building designs—offers substantial potential to increase energy production and reduce environmental impacts. Future research should focus on developing advanced design strategies to enhance turbine integration within urban environments and various architectural forms. This approach represents a significant step toward achieving sustainable energy production and reducing the ecological footprint of urban development.

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Balancing daylight performance and user comfort through pleated folding square façade modules

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Abstract. Increasing energy efficiency and interior comfort, which are sustainable architectural design goals, gains a new dimension with the integration of movable facade systems. The developed facade systems offer the opportunity to increase the efficiency of natural daylight while minimizing unwanted exposure and overheating. In this context, this study focuses on a movable facade system consisting of square modules and investigates the potential of these systems to optimize daylight performance. In the research, a foldable movement mechanism is proposed by using square modules, dividing these modules into sub-triangles and allowing each triangle to exhibit a folding movement within itself. The dimensions, opening angles and movement dynamics of each module, which are activated by the sub-triangles and can be folded and opened without affecting each other's movement, were defined and simulated in detail. After the efficiency of the system was predicted, the system's limitations were evaluated by proposing a folding system with a prototype. Along with the data obtained from the prototype, metrics such as sDA (Spatial Daylight Autonomy), ASE (Annual Sunlight Exposure) and UDI (Useful Daylight Illuminance) were examined in the simulations using Rhinoceros, Grasshopper, Honeybee, Ladybug and Octopus. The results show that the foldable square modules is effective in exposure control with low ASE values and also provides a successful solution in meeting sDA and UDI targets. The study aims to provide a framework for the potential applications of the square module geometry while emphasizing the importance of movable facade systems in sustainable building design.

Keywords: Façade system; Daylight performance; Square modules, Folding movement; Prototype

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1. Introduction

Daylight plays a critical role in sustainable building design because it not only reduces reliance on artificial lighting but also enhances the visual and psychological well-being of occupants (Garcia-Fernandez and Omar, 2023). However, excessive or poorly managed daylight can lead to discomfort, exposure, and increased cooling loads (Pauley, 2004; Wu et al., 2019; Kangazian & Pavazavi, 2023). In parallel, the search for sustainable architectural solutions has become a central focus due to the need to increase energy efficiency, improve indoor environmental quality and reduce the carbon footprint of buildings (Alassaf, 2024; Ma et al., 2023). Among the various strategies used, the integration of movable façade systems has emerged as a promising approach to optimize daylight use while reducing issues such as exposure and solar heat gain (Banihasemi et al., 2015; Hosseini et al., 2019). In particular, movable facades offer flexibility to adapt to changing environmental conditions, improving both daylight performance and user comfort (Hasselaar, 2006; van Hooff et al., 2014; Soudian & Berardi, 2021; Gonçalvez et al., 2024). As seen in the literature, the increasing use of geometric modules offers the opportunity to create complex and movable shading patterns, providing effective control over daylight and solar heat gain (Dastoum et al., 2024). These studies often employ key metrics such as Spatial Daylight Autonomy (sDA), Annual Sunlight Exposure (ASE) and Useful Daylight Illuminance (UDI) are used when evaluating the daylight performance of the proposed and implemented systems.

In these studies in the literature (Neşeliler et al., 2025; Talaei and Sangin, 2024; Kim et al., 2024; Sönmez and Kunduracı, 2021), Spatial Daylight Autonomy (sDA), which is also included in LEED v4.1, in the evaluation of the daylight performance of the proposed and implemented systems, measures the percentage of an area that receives at least 300 lux of daylight in at least 50% of the occupied hours per year; for compliance, at least 40% corresponds to 1 point, 55% to 2 points and 75% to 3 points, Annual Sunlight Exposure (ASE) which can be considered as a complement to the sDA metric, assesses the percentage of a space that experiences illuminance

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levels above 1000 lux for more than 250 occupied hours per year, with less than 10% being the recommended threshold to avoid excessive glare and overheating, and Useful Daylight Illuminance (UDI) divides daylight levels into three ranges: below 100 lux (insufficient daylight), between 100-2000 lux (optimal daylight) and above 2000 lux (excessive daylight that can cause glare and thermal discomfort). A well-balanced daylight strategy typically aims to maximize the percentage of time in the 100-2000 lux range, targeting at least 50% of occupied hours (Nabil & Mardaljevic, 2005; Berardi & Anaraki, 2015; Dabe & Adane, 2018; LEED, 2025). These metrics collectively assess the system's ability to enhance daylight availability while mitigating glare and overheating, contributing to both occupant comfort and energy efficiency.

The development and validation of movable façade systems aimed at improving interior daylight performance require a rigorous iterative process that combines computational tools and physical prototyping. Simulations conducted using Rhinoceros, Grasshopper, Honeybee, and Ladybug allow rapid exploration of design parameters such as module geometry, folding angles, and material properties while predicting performance outcomes under a variety of environmental conditions (Toutou et al., 2018). In addition to these stages, physical prototyping, an artifact that approximates a feature (or multiple features) of a product, service or system (Wood et al., 2001), remains important for testing real-world functionality, assessing mechanical durability and improving user interaction. By combining digital and physical testing, this dual approach ensures that theoretical optimizations align with practical applicability, encouraging both high-performance and constructible innovations.

This study investigates the potential of a movable façade system consisting of square modules that use a folding motion to control daylight penetration and distribution. A foldable and movable façade system consisting of square modules divided into smaller sub-triangles, each of which can move independently, is proposed. This design allows for a folding movement where each module can adjust its orientation and opening angle without interfering with adjacent modules. Rhinoceros, Grasshopper, Honeybee and Ladybug computational tools are used to simulate and analyze the daylight performance of the proposed system. Through detailed modeling and simulation, the research first examines the base case scenario, which is a generic office proposed within the scope of the study, and then investigates the relationship between the geometric configuration of the square modules, the movement dynamics and the resulting daylight conditions. In parallel with this process, a prototype of a single module within the multiplied square modules was developed to understand the mobility and limitations of the module through physical modeling and revisions to this model. The combined use of prototypes and simulations allows the system to be evaluated not only theoretically but also in practical conditions. This two-way approach aims to increase the chances of providing an efficient solution.

The findings aim to demonstrate the effectiveness of foldable modules in meeting the exposure control and daylight performance targets of the interior. The analysis of different configurations within the system was completed by evaluating the previously determined metrics. The aim is to obtain multiple configurations where these metrics exceed thresholds. This supports the concept of movement of the system while also offering the user different usage alternatives in different periods. This study aims to contribute to the growing body of knowledge on movable façade systems by examining the intersection of geometry, movement and daylight performance.

2. Method of the Study

The study is based on 3 main stages, each of which has subcategories (Fig. 1). The first stage was determined as designing a façade system by proposing square folding façade modules using Rhinoceros and Grasshopper and applying this system to a generic space. After the system was implemented, Honeybee and Ladybug were used in addition to Rhinoceros and Grasshopper in order to make initial observations regarding the efficiency of the system. At this stage, the number of parameters was intentionally limited to be detailed in later stages. The second main stage is related to determining the movement constraints of the system designed with one and two-dimensional elements in order to perform the initial simulations and to have an idea about the efficiency of the system and the arrangements regarding the effect of these constraints on the daylight performance of the system. In order to observe these constraints and to examine the folding movement of the system in real life, the scope of this stage a 3D model was created regarding the movement of the module by modeling a triangular section inside the square module in 3D. After this prototype was produced, movement constraints were determined on the model printed with a 3D printer. Thus, the first and second stages were combined, and the simulation was revised by revising the parametric model and the number of parameters. The final stage aims to optimize the use of daylight in the interior space by using Octopus to ensure user comfort through the separate movement of each element of the revised system.

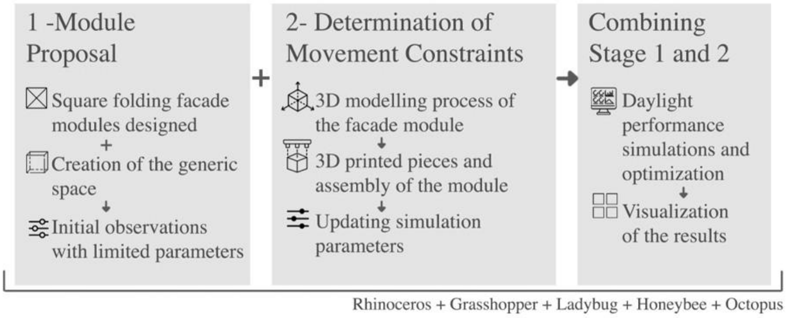

Fig. 1. Stages of the Study

2.1. Module Proposal and Initial Daylight Performance Results

In Phase 1, two stages were carried out simultaneously. While a generic space was defined, the modules forming the façade system were also suggested.

As the first stage, a generic space with a glazed south façade was modelled using Rhinoceros, providing a context for testing and iterating the proposed modules. For this, a standard office area was defined, and a parametric model was created. The depth of the proposed office structure was defined as 5.5 meters, the façade width as 7.2 meters and the height as 3.85 meters. Each surface was defined as different layers within itself, and different material values were provided (Table 1) with Grasshopper and Honeybee according to LEED v4.1 standarts (LEED, 2025). The south facade of this office building was defined as a glass facade and the ratio of the glass surface to the wall on the 7.2mx3.85m facade was determined as 75.7% with the glass portion measuring 7mx3m. According to LEED v4.1, the ceiling was defined to have a reflectance value of 80%, the wall 50% and the floor 20%.

In order to evaluate the interior daylight performance in the base scenario, i.e. without a façade system, an analysis grid was defined at 0.6 m intervals at ground level and 0.76 m above the floor. This grid was used to assess sDA, ASE, and UDI values at each stage.

In parallel with this process, a module creation was developed based on square geometry to create the façade system. This square geometry was divided into sub-sections and a module exhibiting a folding movement was produced (Fig. 2). In the production phase of this module, the edge midpoints and corner points of each triangle were defined. By combining these points, a total of eight right triangles were obtained in the square. The 45-degree angle of these triangles corresponding to the center of the square was divided into 4 equal angles and 4 more sub-triangles were defined. These sub-triangles formed the panels that would exhibit a folding movement. A parametric model was then constructed in which the folding movement was achieved by moving each right edge of each triangle toward its hypotenuse.

After these two stages were completed, modules were deployed on the façade, with a total of 21 modules used. In addition to the full modules, half modules can also be proposed depending on the facade length and width. The movement angles of the modules were defined in 5-degree increments to reduce simulation time.

Table 1. Simulation Parameters

Location	İzmir, Türkiye	Window Transmittance	40%
Orientation	South	Work Plane Height	0.76m
Office Dimensions	H: 3.85m W: 7.2m L: 3.5m	Simulation Grid Spacing	0.6m
Window Dimension	H: 3m W:7m	Parameters	Folding angles (x*5)
Reflectance Values	Ceiling: 80% Floor: 20% Walls: 50% Façade Elements: 40%	Objectives	sDA, ASE, UDI

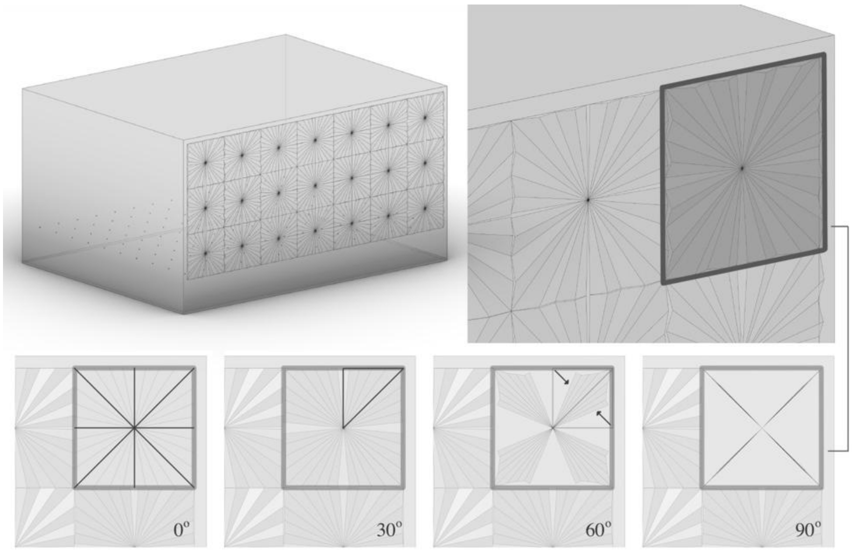

Fig. 2. Generation and Arrangement of Modules

Before testing the prototype of the model, the daylight performance of the proposed interior space and the initial evaluation of the system were conducted. In the base case without the façade system, the results were: sDA 100%, ASE 88.57%, and UDI 41.04%.

Following this stage, the system was applied to the façade. Prior to detailed analysis, a preliminary test was conducted in which all panels moved simultaneously at 10-degree and multiple-angle intervals, providing initial performance predictions.

Table 2. Initial Daylight Performance Analysis

Angle	sDA	ASE	UDI
0	0	0	71
10	0.01	0	64
20	10	0	46
30	43	16	36
40	67	31	31
50	94	47	29
60	100	56	28
70	100	64	27
80	100	72	26
90	100	75	26

*All values are in percentages

This analysis reveals that configurations where all modules are positioned at 30 and 40 degrees have a high probability of producing efficient results in terms of sDA (Spatial Daylight Autonomy), ASE (Annual Sunlight Exposure) and UDI (Useful Daylight Illuminance) measurements. Within the scope of this analysis, it was predicted that by varying the module angles exhibiting total movement with individual movements in other stages, it would provide an advantage in terms of comfort by ensuring the optimal use of natural light in the interior while also balancing excessive sunlight exposure. These positive results proved the reliability and effectiveness of the configuration determined at this stage of the design, and formed a basis for the transition to the next stages of the study. Therefore, physical module production was carried out after this step.

2.2. Modelling and Prototyping Process

After the possible efficiency of the system was predicted, the prototyping phase was initiated. This stage, composed of interrelated steps involving iterative feedback, focused on one of the eight identical triangles within the square module. Initially, the folding mechanism was designed to operate by sliding the ends of the panels along a rail. However, this method did not enable a uniform folding motion; instead, it merely gathered the panels. As a result, this approach—tested using A4 paper and cardboard—was not implemented further.

As the next stage, a scissor system was proposed so that each panel could be folded at an equal angle. However, the problem here was that the panels could not be attached to the scissor system due to the change in the distance from the center and the diameter lengths in the scissor system.

As the last stage, one of the joints was planned to move in a guide (Fig. 3). This configuration successfully enabled uniform panel movement, achieving the desired folding motion. Thus, the targeted behavior was realized by the end of the third prototype iteration (Fig. 4).

The components of the modules—including nuts and bolts, panels, elements of the scissor mechanism, and connecting parts—were produced using a 3D printer. Hinges were modeled for the panel edges that are adjacent and designed to rotate; however, paper tape was used to allow quick and flexible movement testing. The parts were printed using a Bamboo Lab A1 3D printer with PLA+ filament, 1.75 mm in diameter.

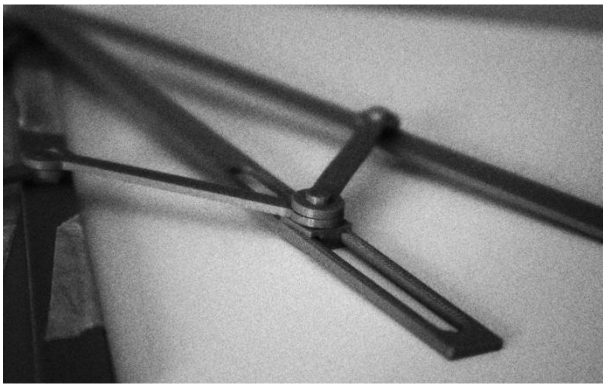

Fig. 3. Sliding Joint Detail

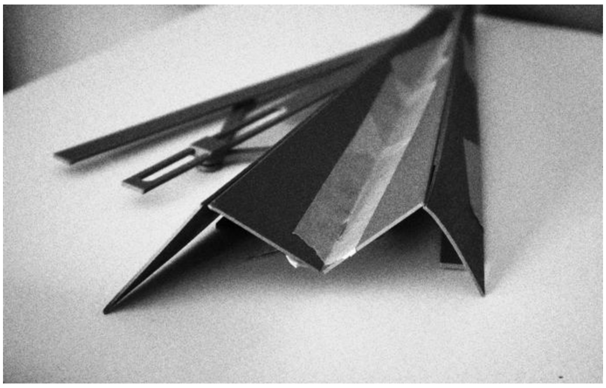

Fig. 4. General View of the System and Panel Plates

During the movement of the module, the sliding joint shifts position and supports the panels to remain fixed. However, a key limitation of the study is that when scaled with the computational model, the material thickness and the connection parts of the scissor system can close up to 80 degrees instead of 90 degrees as targeted.

Two important information obtained at this stage is the ability of the panels to provide equal folding and the closing angle. These inputs were collected to be used in the next stage and the simulation parameters were updated according to this information.

3.3 Daylight Performance Analysis Based on the Physical Model

The movement angles of the panels were updated in the slider in the Grasshopper interface to increase by 5 and multiples between 0-80. The material and permeability values were kept the same for consistency with the first simulation. Since the parameters were updated at this stage, unlike the first simulation, panel ID numbers were assigned to the 21 modules on the façade, and each was moved with different sliders (Fig. 5). Thus, each module can move at different angles within itself, thus supporting the formation of configurations aimed to provide alternatives to the user. For this reason, since the possibilities of each panel at 5-degree positions between 0-80 cannot be tested one by one, the Octopus plugin was included in the Rhinoceros, Grasshopper, Ladybug and Honeybee plugins at this stage. Thus, simulations were performed by defining each panel angle as a parameter and sDA, ASE and UDI values as objectives. Optimization was started with the population size 55 and max generation 15 values. In order to be able to examine all the configurations in the table later, all sliders and result information were recorded with the Data Recorder component.

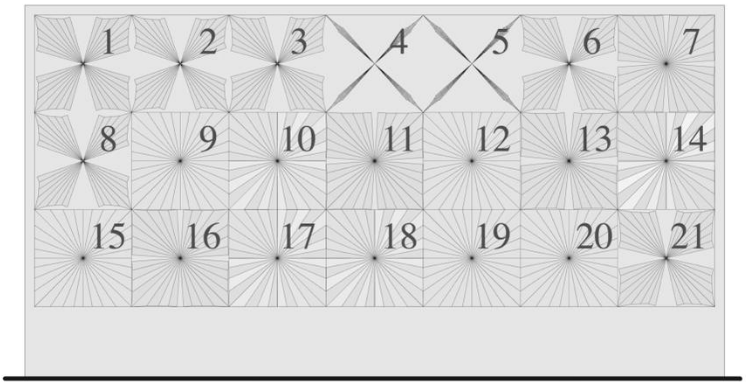

Fig. 5. Module IDs

As a result of the optimization, more than 800 configurations were obtained. All values were compiled into a table and organized. First of all, configurations with sDA values below 40% and ASE values above 10% were eliminated. The results were ranked by writing a formula that kept the weight and importance of all metrics equal. The ten most efficient configurations and the results obtained are given in Table 3.

Table 3. Selected Configurations and Results

Results			Module IDs																				
sDA	ASE	UDI	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
			Angular States of the Modules																				
90.0	9.3	65.5	0	25	40	15	0	10	30	20	0	15	40	5	20	10	75	55	65	55	75	20	80
90.0	9.3	65.4	0	5	5	5	40	5	45	55	0	5	30	5	30	10	0	80	80	65	40	40	80
89.3	7.9	65.4	0	0	5	5	35	5	45	55	0	5	30	5	30	10	0	80	80	60	40	40	80
87.9	9.3	65.3	0	5	45	0	45	10	5	5	5	10	15	5	5	20	10	80	80	75	15	55	75
87.1	7.1	65.2	5	25	20	10	5	15	25	20	55	0	50	5	5	15	50	70	35	20	55	80	80
85.7	7.9	64.9	25	0	60	5	10	25	0	20	5	60	5	5	20	25	50	45	60	50	55	55	75
83.6	9.3	65.2	10	10	45	0	45	20	5	5	5	5	10	5	5	20	10	80	80	75	20	25	75
86.4	5.7	65.2	10	30	20	10	5	10	25	20	50	5	50	5	5	15	50	70	35	20	55	80	80
84.3	7.9	65.0	0	20	20	0	5	5	45	20	50	5	50	5	30	10	50	70	35	15	40	80	80
83.6	7.9	65.2	0	5	5	5	40	5	45	55	0	5	25	0	30	10	0	55	80	70	40	40	80

*sDA, ASE and UDI values are in percentages

From the obtained results, the first configuration was visualized and detailed. The obtained results were sDA value 90%, ASE value 9.3% and UDI value 65.5%. This proves that efficient configurations can be obtained even though the system has limitations.

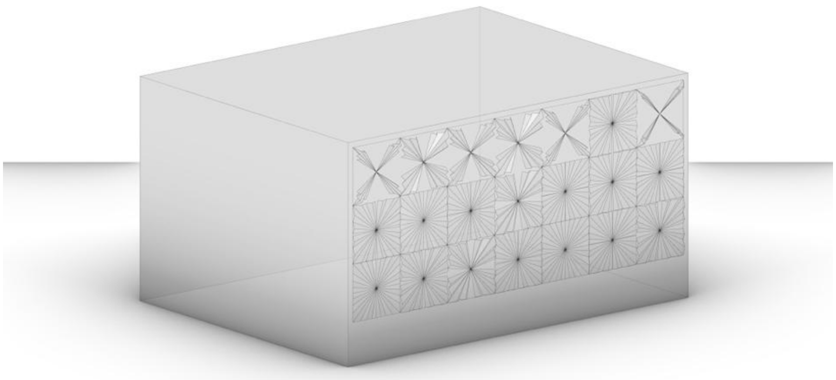

Fig. 5. Selected Optimal Configuration

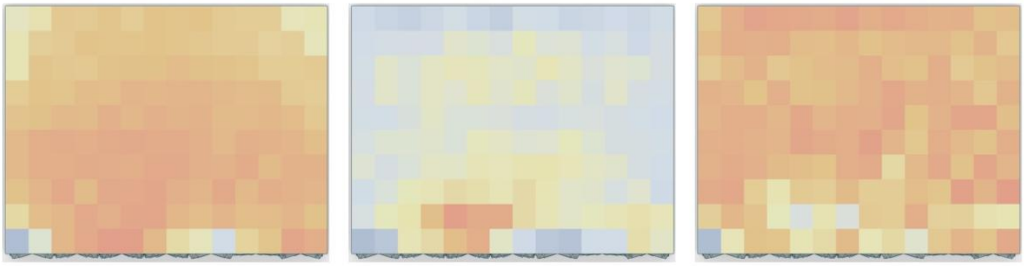

Fig. 5. Selected Configuration and Daylight Performance Results

4. Conclusion

This study focuses on the potential of movable façade systems in line with the goal of improving indoor environmental quality, at a time when sustainable architectural solutions are increasingly gaining importance in today's design approaches. In particular, the effect of a movable façade system consisting of square modules and controlling daylight penetration with a folding movement on optimizing indoor daylight performance was evaluated in detail. The study was carried out by combining methods, using digital simulations and physical prototype production. In this process, the key metrics sDA (Spatial Daylight Autonomy), ASE (Annual Sunlight Exposure) and UDI (Useful Daylight Illuminance), which are also included in LEED v4.1 standards, were used to evaluate the daylight performance of the proposed system. The base case scenario revealed that there were excessive sunlight exposure problem in the indoor space, which once again emphasized the necessity of a movable façade system. By defining certain stages, the simulations were updated after testing how the proposed system would work in a real-life scenario. Different configurations of 21 modules were examined with the individual movement of each module. The most efficient configuration obtained stood out with sDA 90%, ASE 9.3% and UDI 65.5% values. These results proved that the system can offer highly efficient configurations despite the specified limitations and can effectively control exposure problem while using daylight at an optimal level in the interior.

In general, this study has revealed the potential of movable facade systems to improve daylight performance and increase user comfort; it has examined the relationship between geometry, movement and daylight performance. The proposed system has provided flexibility by offering users various configuration alternatives in different usage periods and environmental conditions. In addition, this two-way approach combining digital simulations and physical prototyping has enabled this study to harmonize theoretical optimizations with practical applicability.

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The impact of thermal insulation on energy savings and thermal comfort: a study in multi-story residential buildings

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Abstract. Energy-efficient building design is achievable by thoughtfully evaluating and cohesively integrating the most suitable values for various variables. Energy-efficient building design is possible by considering the most appropriate values for many variables and bringing them together harmoniously. In our country, especially with the entry into force of the Energy Efficiency Law, studies carried out for efficient energy use have become even more important. In this context, a rapid increase has been observed in external insulation applications, especially in buildings, for increasing energy performance and saving energy. While external insulation applications provide energy savings, they are also effective in improving the user's thermal comfort conditions.
Studies, particularly those addressing heating energy demands during cold periods, prominently focus on ensuring thermal comfort and enhancing energy conservation in buildings. This study evaluates user behaviors related to energy consumption, measures taken, and satisfaction levels in achieving the desired thermal comfort in indoor environments during cold seasons. The primary aim is to emphasize the significance of external insulation applications as a key strategy for energy savings in residential buildings. In this context, a survey was conducted in two apartment buildings within a multi-story residential complex to assess the impact of two different wall constructions' insulation performance on thermal comfort satisfaction. The survey results indicate that external insulation applications positively influence energy savings and enhance users' thermal comfort satisfaction. The findings demonstrate that effective insulation practices reduce building energy consumption and contribute significantly to the national economy.

Keywords: Energy efficiency, Energy efficient retrofit, Thermal insulation, Thermal comfort.

1. Introduction

While the energy demand is constantly increasing globally, the depletion of fossil fuel reserves raises serious concerns about possible future energy supply problems. Although this situation can be solved in the short term by finding new energy sources and making them sustainable, another solution is to reduce the consumption momentum and use the existing energy more efficiently. In this context, it is a fact that has been revealed by scientific studies that significant energy savings can be achieved by improving energy performance in the building sector. When it comes to the evaluation of building performance, the criteria on which the energy efficiency of the building will be determined should be defined by standards, and the application conditions should be explained by guidelines. Within the framework of the concept of energy-efficient building, each country has standards, regulations, and policies developed within its local conditions. Building energy regulations and standards help to realize the potential for energy conservation in buildings and to increase the demand for energy-efficient design in buildings. This also forms a basis for the development of energy-efficient policies (Harputlugil, 2013). In Türkiye, legal regulations regarding energy efficiency have gained momentum within the framework of the harmonization process with the European Union. In this context, the Energy Efficiency Law was adopted in 2007, creating a legal basis for energy saving. In line with the law, the Energy Performance in Buildings Regulation, which entered into force in 2010, aimed to increase energy efficiency in buildings and made it mandatory to issue energy identity certificates for all existing and new buildings. In addition, the TS 825 "Thermal Insulation Rules in Buildings" standard, which determines the technical principles regarding thermal insulation in buildings, was made mandatory in 2000, thus increasing the importance of thermal insulation.

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In residential buildings, significant heat losses occur during the winter months, and substantial heat gains are observed in the summer. However, both contractors and building occupants typically overlook these issues, focusing primarily on the aesthetic and visual appeal of the building. As a result, during the construction phase, the selection of inappropriate building materials and the failure to implement essential applications can have negative environmental impacts, leading to increased energy consumption over the lifespan of the building. In this context, despite the high energy consumption, the building sector holds the greatest potential for energy and emission savings compared to other sectors (Fig. 1). Given the high potential for low-cost energy savings within the building sector, it has emerged as a priority area for energy efficiency (Mıhlayanlar & Meral, 2023).

The building envelope plays a crucial role in meeting the basic needs of the user, as well as contributing to energy conservation, air quality, and mitigating global warming. However, additional artificial energy systems are often required to control climatic effects during certain times of the year. In contemporary settings, the depletion of energy resources, which serve as inputs for these systems, and the corresponding increase in costs, have made the efficient use and conservation of energy imperative.

When analyzing energy consumption patterns in buildings, it is observed that 65% of the energy is used for heating, cooling, and ventilation, 20% for lighting, and 15% for other systems (URL-1), (Fig. 2). The construction sector, accounting for 33% of total energy consumption, holds significant potential for energy savings. The sector's high energy consumption highlights the increasing importance of insulation in energy conservation efforts. Therefore, in modern buildings designed with an emphasis on conscious energy use and equipped with suitable materials and architectural details, effective solution proposals should be developed by considering the alignment of the final products with energy policies, within the context of the owner-designer-contractor-user relationships.

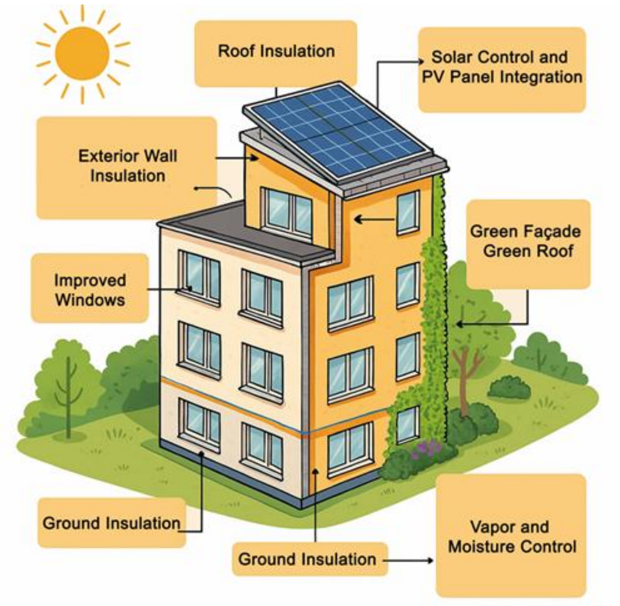

Fig. 1. Energy saving potential in buildings

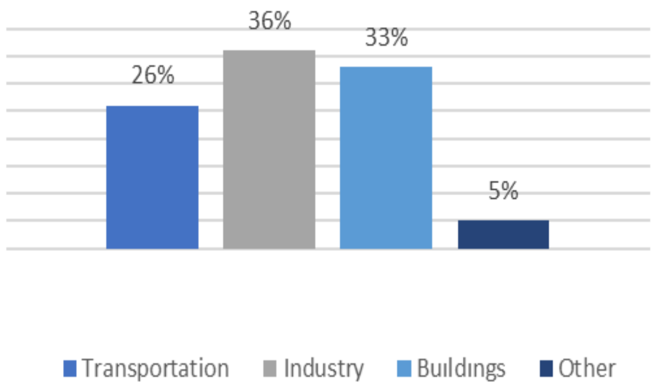

Fig. 2. Total Energy Consumption Rates in Türkiye, (URL-1)

To achieve energy conservation in buildings, it is essential to provide the desired indoor climate with minimal fuel consumption. At this point, thermal insulation is the most critical building requirement that minimizes fuel consumption while simultaneously ensuring indoor climatic comfort. Thermal insulation should be implemented to extend the lifespan of the building, to provide users with comfortable and healthy spaces, to save on heating and cooling costs during the building's use, and to achieve the same level of energy efficiency. Furthermore, thermal insulation enables occupants to experience desired thermal comfort in spaces while using less energy. In cases where the necessary thermal insulation is not applied or is applied incompletely, the comfort temperature of the indoor environment will never reach the desired level. As a result, inappropriate air currents arise within the interior, which reduces the comfort level of the space. By applying appropriate insulation, the surface temperature of the interior walls is increased, and optimal environmental conditions are established. Through the conscious decisions made by architects during the design phase, buildings' dependency on non-renewable energy sources can be reduced, and economic losses and potential negative environmental impacts can be significantly mitigated (Canan & Bakır, 2003). Considering the energy challenges faced by our country, insulating the building envelope has become inevitable for consuming less energy and providing thermal comfort within interior spaces. In recent years, building envelope insulation has emerged as a crucial component of the construction sector to minimize energy consumption (Aydın, 2011).

1.1 Energy-Efficient Retrofitting in Buildings

In recent years, increasing awareness of environmental sustainability along with increasing energy costs necessitates the development of more conscious, holistic, and systematic approaches to increase energy efficiency in buildings. In this context, improving the energy performance of buildings not only contributes to reducing energy costs but also has great importance in terms of reducing greenhouse gas emissions and minimizing environmental impacts.

Energy-efficient renovation in existing buildings is expressed in the literature with terms such as "energy efficient retrofitting," "reinforcement," and "efficiency renovation." In this process, a detailed analysis of the current condition of the building should be carried out through on-site inspection, observation, and calculations. Packages containing appropriate combinations of retrofit measures should be determined, tested, and their effectiveness should be compared to decide on the most suitable options (Atmaca & Yılmaz, (2019); Liu vd., (2020); Ma vd., (2012); Mıhlayanlar & Meral, (2023). Evaluations based on criteria such as sustainability, life cycle, and cost-effectiveness are of critical importance in this selection process. In addition, building typology, climate conditions, building envelope features, mechanical systems, lighting, and renewable energy integration should be addressed with an integrated approach to making buildings energy efficient.

Table 1. Energy-efficient retrofit recommendations for buildings (ÇŞB, 2015)

External Wall Insulation	• It is recommended to insulate the exterior with materials such as XPS / EPS, which have a low thermal conductivity coefficient.	
Solar Control	• Passive solar gain is provided on the south facade, while external sunshade systems are recommended on the west and east facades. • Reflective film or Low-E glass can be used on the windows.	
Green Facade and Roof (Advanced Application)	• Green facade elements or roof gardens are recommended to reduce energy loads.	

Table 1 continued

Solar Energy Systems (PV Panel Application)	• Part of the building's electricity needs can be met with solar panels placed on the roof. A sloping position on the south facade is recommended.	
Roof Insulation	• Thermal insulation should be made on the roof with materials such as rock wool or glass wool, at least 10 cm thick. • Reflective surface coatings should be added to the insulation on flat roofs.	
Ground Floor	• Thermal insulation should be applied to the floors that come into contact with the ground, and details that will reduce sound and heat transfer should be considered in the flooring between floors	
Improvement of Window and Door Systems	• Existing single-glazed joinery should be replaced with heat-insulated double or triple-glazed systems. • Thermally broken aluminum or wooden joinery is recommended instead of PVC. • Window seals should be renewed to ensure sealing.	
Air Tightness	• Air leakage should be prevented with sealing tapes and filling materials at the building shell joints, window, and door connections.	

2. Method

Efforts to ensure thermal comfort and enhance energy conservation in buildings primarily focus on heating energy consumption during cold periods. This study evaluates user behaviors related to energy consumption, the measures they adopt, and their satisfaction levels in achieving the desired thermal comfort in indoor environments during cold seasons. The significance of external insulation applications, implemented to improve energy efficiency in residential buildings, is emphasized as a key aspect of this research.

The study area consists of 12-story residential buildings (Fig. 3). When the two residential buildings were first built, the insulation applied was double-wall thermal insulation. In one of the two blocks, external insulation was applied 3 years ago to save energy, considering the increasing energy costs. The research methodology involved a systematic sampling approach and a survey administered to a selected group of residents. The sample group was determined based on specific criteria, focusing on the thermal comfort satisfaction of individuals living in the two buildings. While one building retained only cavity wall insulation, the other had an additional layer of external insulation applied to the same wall construction. The primary aim of the study was to assess the impact of these two different wall constructions on insulation performance and thermal comfort satisfaction.

Fig. 3. Insulated and uninsulated residential buildings

The survey, distributed to residents of the selected buildings, covered various topics, including perceptions of thermal comfort, satisfaction with energy consumption, and the impact of insulation applications. The survey forms were distributed to apartments on the ground and standard floors of the buildings. Particular attention was given to selecting participants who had lived in their apartments for at least two years. This criterion ensured that respondents were familiar with their living environment and had experienced at least two heating seasons, enabling them to provide more informed answers. In total, 36 participants were surveyed.

The survey aimed to analyze four main factors to evaluate the impact of external insulation on comfort:

- Economic satisfaction,
- Comfort satisfaction,
- Priorities in heating.

The survey responses collected from the building residents were subjected to statistical analyses, and the findings were evaluated and interpreted based on the results.

3. Findings

This study aimed to assess the impact of thermal comfort conditions on user satisfaction in both insulated and uninsulated buildings. To achieve this, survey results collected from users were analyzed and presented as percentages and graphical representations using the Excel program. The data obtained were interpreted to provide a detailed examination of user satisfaction and preferences.

According to the survey results, 66% of the participants identified as female, while 33% identified as male. In terms of age distribution, 8% of participants were in the 20-29 age range, 19% in the 30-39 age range, 36% in the 40-49 age range, 8% in the 50-59 age range, and 28% were aged 60 years or older. Regarding educational attainment, 5% of participants reported being literate, 11% were primary school graduates, 25% were high school graduates, and 58% were university graduates. In the evaluation of participants' employment status, it was found that 36% were unemployed, 50% were employed, and 13% were retired. Regarding the duration of residence, 19% had lived in their current residence for 1-4 years, 19% for 5-9 years, and 61% for 10-14 years.

In the assessment of sunlight exposure in the residences, 66% of participants reported that their homes receive sunlight, 5% stated that their homes do not, and 28% indicated that their homes partially receive sunlight. Overall, a large portion of the participants have residences that benefit from sunlight, but there may be a need to increase access to sunlight for more buildings and residential areas.

In the evaluation of heating system satisfaction, 73% of participants residing in insulated buildings reported being satisfied with the current heating system, 20% indicated being mostly satisfied, and 7% expressed moderate satisfaction. In the evaluation of users residing in uninsulated buildings, 38% reported being satisfied, 33% expressed being mostly satisfied, 10% indicated moderate satisfaction, 10% noted slight satisfaction, and 10% stated that they were not satisfied. (Fig. 4). The findings show that users living in insulated buildings generally have higher satisfaction levels in terms of thermal comfort.

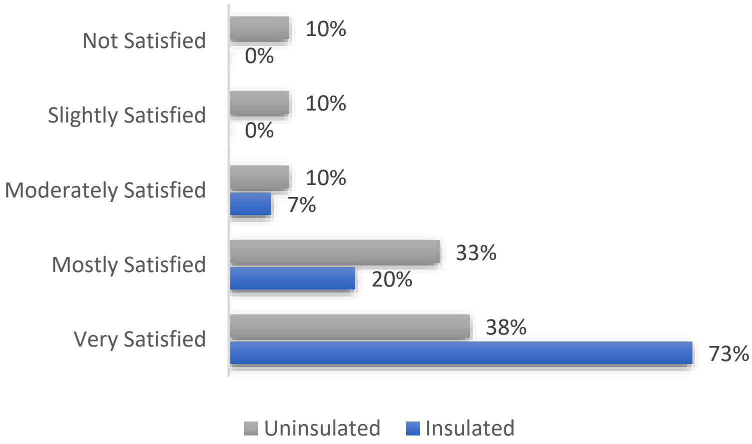

Fig. 4. Satisfaction level with the heating system

In the survey, participants were asked, "Do you use additional heating devices (electric heater, stove, air conditioner, electric radiator, etc.)?" Among users residing in insulated buildings, 20% responded affirmatively, while 80% indicated that they do not use additional heating devices. In contrast, all users living in uninsulated buildings (100%) reported that they do not use additional heating devices. This finding suggests that thermal comfort can generally be achieved in insulated buildings without the need for supplementary heating devices, whereas the need for such support appears to be absent in uninsulated buildings.

Participants who answered "yes" to the question "Do you use additional heating devices?" were further inquired about the circumstances under which these devices were used. Forty percent of the participants reported using additional heating devices when the weather was colder than seasonal norms, 20% used them during the evening hours, and 40% used them both when the weather was colder than seasonal norms and during the evening hours. These data suggest that the use of additional heating devices is influenced by both weather conditions and specific times of day.

Participants' behaviors regarding the use of combi boilers were assessed through a multiple-choice question. Among participants residing in insulated buildings, 40% indicated that they use the combi boiler at the same level during both day and night, while 30% stated that they use it at different levels during the day and night. In contrast, among participants living in uninsulated buildings, 31% reported using the combi boiler at the same level throughout the day and night, and 27% reported using it at different levels depending on the time of day (Fig. 5). These findings suggest that combi boiler usage habits may vary based on the insulation status of the building.

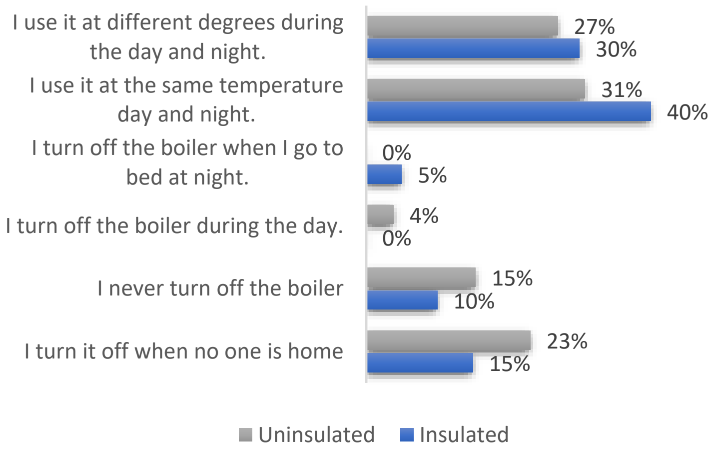

Fig. 5. Combi boiler usage behavior

Participants were asked whether they used room thermostats or thermostatic valves. Among those residing in insulated buildings, 80% reported not using such devices, while all participants (100%) living in uninsulated buildings stated that they did not use them. This indicates that the use of room thermostats or thermostatic valves is not common in either type of building.

Participants were also asked about the factors they prioritize when using combi boilers. Among users living in insulated buildings, 47% indicated that "heating satisfaction" was their primary concern, 27% prioritized "economy," and 27% prioritized "children." In contrast, 57% of users in uninsulated buildings identified "heating satisfaction" as their main priority, 29% prioritized "economy," and 14% prioritized "children." These findings suggest that the insulation status of the building can influence users' priorities when using combi boilers (Fig. 6).

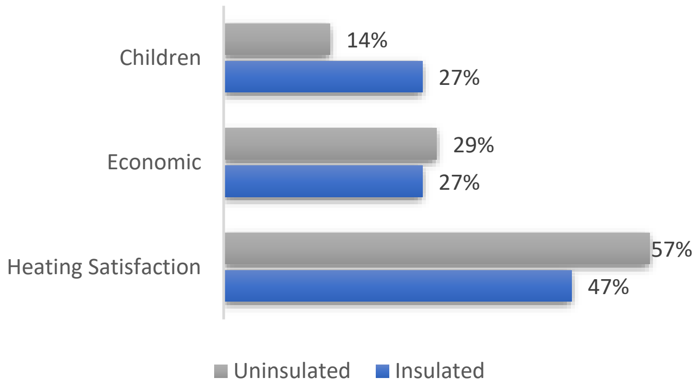

Fig. 6. Priority of combi boiler usage

The relationship between the amount of money spent on heating and participants' heating satisfaction was assessed. Among users living in insulated buildings, 33% responded, "I spend little, I get very warm," while 38% of users residing in uninsulated buildings responded, "I spend a lot, I get moderately warm" (Fig. 7). These findings indicate that insulation has a positive impact on the relationship between energy expenditure and heating satisfaction.

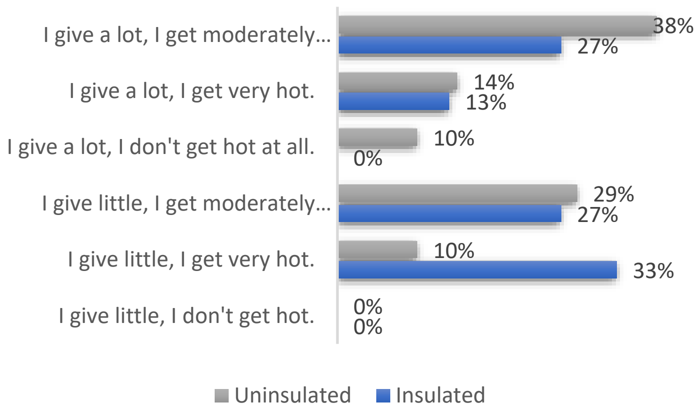

Fig.7. Economic contentment

Survey participants were asked whether the radiators in their homes were turned on. The majority of participants reported that the radiators were generally on; however, 22% indicated that the radiators in their bedrooms were turned off (Fig. 8). This suggests that some users have made adjustments that may limit thermal comfort in specific areas of their homes.

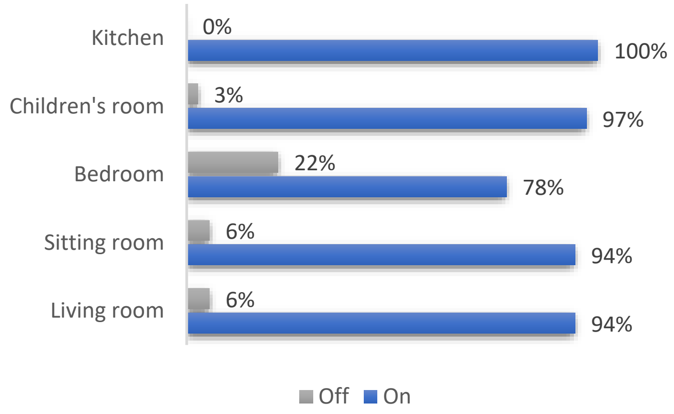

Fig. 8. Whether the front of the heaters is turned on or off

The survey inquired whether participants had made any modifications to the dimensions of their radiators, to which all participants in both building types responded "no." Additionally, the status of thermal insulation implementation was assessed. Among participants living in insulated buildings, 40% reported having installed thermal insulation, while 14% of those in uninsulated buildings indicated that they had done so. Furthermore, 19% of participants in uninsulated buildings expressed that they were considering implementing thermal insulation (Fig. 9). These findings suggest that individuals residing in uninsulated buildings exhibit lower levels of awareness or application of insulation measures.

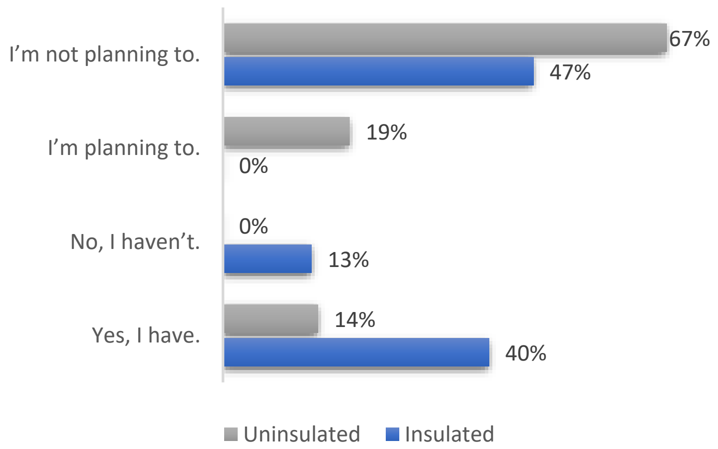

Fig. 9. Supplementary thermal insulation

Survey participants were asked about their current insulation practices. Among those residing in insulated buildings, 86% reported insulating the exterior, while 14% insulated the balcony door. In contrast, 33% of participants living in uninsulated buildings indicated that they had insulated the exterior walls, window sashes, and balcony doors.

Among users considering additional insulation in uninsulated buildings, 50% planned to insulate the exterior walls, 10% intended to insulate the windows, and 20% aimed to insulate the balcony door (Fig. 10). These findings suggest that there is both awareness and a growing trend of insulation application in uninsulated buildings.

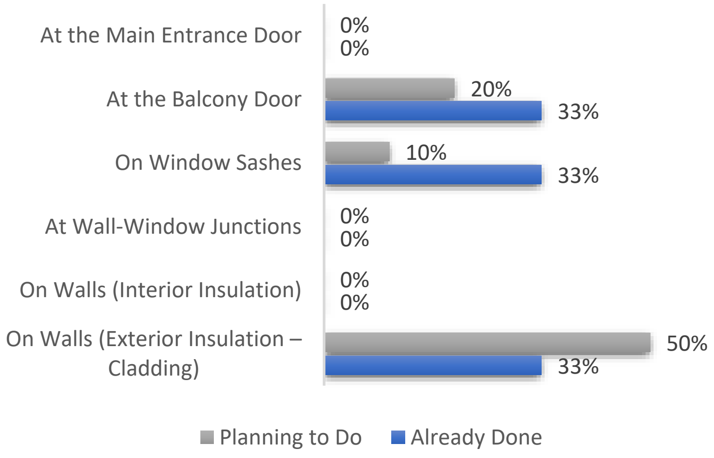

Fig. 10. Supplementary thermal insulation in uninsulated buildings

The satisfaction levels of survey participants regarding the heating conditions in their homes were assessed. Among those living in insulated buildings, 67% reported being satisfied with the heating conditions, 27% were mostly satisfied, and 7% were moderately satisfied. In contrast, among participants residing in uninsulated buildings, 33% reported being mostly satisfied, 29% were satisfied, 24% were moderately satisfied, 10% were not satisfied, and 5% were slightly satisfied (Fig. 11). These results indicate that users living in insulated buildings have a higher level of satisfaction with their heating conditions.

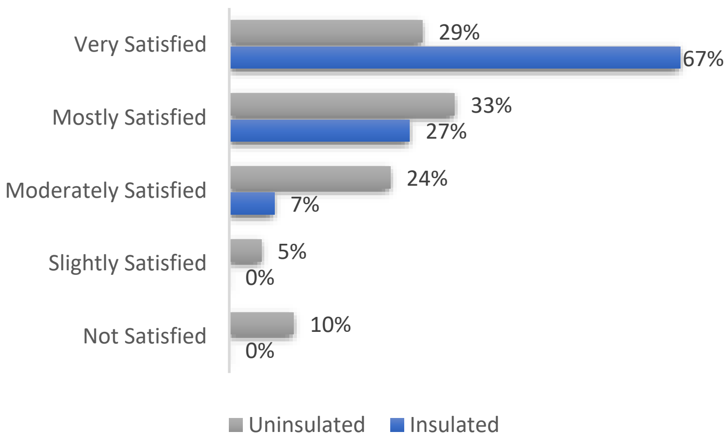

Fig. 11. Heating satisfaction

Finally, participants residing in externally insulated buildings were asked, "Did your natural gas bill decrease after the external insulation application?" To this, 27% of the participants responded "yes," 20% answered "no," and 53% indicated "partially." However, the majority of users reported that they were unable to observe a reduction in their bills due to the increase in energy prices.

4. Discussion

In this study, conducted in a multi-storey residential complex in Trabzon province with varying external wall constructions, the evaluation of users' thermal comfort and economic satisfaction levels led to the following findings:

• It was observed that a significant majority of users in the building with external insulation were satisfied with the heating system, in contrast to users in the other buildings.

• Although additional heating devices were used in the insulated building, participants reported using them when the weather was colder than seasonal norms, during seasonal transition periods, and in the evening hours. It is hypothesized that users residing in uninsulated buildings avoid using additional heating devices due to concerns about the potential increase in their natural gas bills.

• It was observed that the majority of users in both insulated and uninsulated buildings utilize the combi boiler at equal levels during the day and night. This behavior is believed to be motivated by users in insulated buildings who prefer consistent use, either to avoid the increased energy consumption associated with frequently turning the combi boiler on and off or to maintain a constant indoor temperature. In uninsulated buildings, this pattern is thought to stem from the desire to prevent discomfort caused by rapid drops in ambient temperature, in addition to the reasons mentioned above.

• When participants were asked about the use of room thermostats or thermostatic valves, it was found that 80% of users in insulated buildings and all users in uninsulated buildings did not use such equipment. This suggests that users may lack awareness of these control systems, which are designed to enhance energy efficiency, or do not possess sufficient knowledge regarding their functions and benefits.

• An analysis of the relationship between heating costs and heating satisfaction revealed that in uninsulated buildings, heating costs are high while the heating level remains moderate. In contrast, in the insulated building, heating costs are low and heating satisfaction is high. These findings indicate that heat losses are significant in uninsulated buildings, leading to economic strain and discomfort for users. At the same time, insulation directly contributes to improved energy efficiency and greater heating satisfaction.

• It was found that the vast majority of users living in uninsulated buildings do not implement any insulation measures, and most do not plan to consider such measures in the future. Among the few who contemplated additional insulation, the focus was primarily on insulating the external walls and balcony doors. This situation is believed to be related to users' reluctance to assume the additional financial burden associated with insulation.

• In the priority assessments, it was observed that most users in both building types prioritized thermal comfort satisfaction. Specifically, 67% of users in insulated buildings reported being satisfied with their heating, while 33% of users in uninsulated buildings expressed being mostly satisfied.

5. Conclusions

These results show that insulated buildings offer advantages in terms of thermal comfort and energy efficiency. Considering the positive effects of external thermal insulation on user satisfaction in the existing multi-story residential block, a series of suggestions have been developed for energy-efficient improvement studies. First of all, it has been observed that external thermal insulation application increases the thermal comfort and economic satisfaction of users. In this context, external facade insulation should be encouraged in uninsulated buildings, aiming to reduce energy losses and increase user satisfaction. It is important to raise users' awareness about the energy-saving and long-term economic advantages of insulation applications. For this purpose, awareness about insulation can be increased by organizing training programs and encouraging users to make such investments. In addition, introducing incentive mechanisms such as state support, tax reductions, or low-interest loans to reduce insulation costs will make insulation more accessible.

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Investigation the effect of kinetic shading elements on reducing cooling loads

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Abstract. Today, the energy used for heating, cooling, and lighting in buildings constitutes the majority of a building's total energy consumption. Especially since the 2000s, architects have focused on the design of shading elements to provide the optimum values required for the thermal and visual comfort of indoor spaces. Kinetic shading elements have been considered the most effective solution within the scope of this study, as they can be designed according to the climatic conditions of the building's environment and can be quickly controlled through today's technological simulation tools to evaluate how they respond to variable parameters. Evaluating the purpose of using kinetic shading elements and their suitability according to variable parameters in the design process is highly important in terms of the performance of the design. Therefore, in this study, design parameters, dependent and independent variables affecting the design, design tools, methods used for optimization, and the results of numerous studies conducted in recent years for different purposes have been examined. As a result, based on the evaluations of the reviewed studies, this study has identified the design criteria and their importance that designers should pay attention to in the design process of kinetic shading elements. It is observed that the outcomes obtained from the examined studies achieve optimum values in line with their objectives through kinetic shading elements. In this way, the discipline of architecture contributes to the ongoing energy crisis today by reducing the energy consumption of buildings.

Keywords: Kinetic Shading Elements, Parametric Design, Cooling Loads of Buildings, Sustanibility.

1. Introduction

Today, factors such as population growth, industrialization, and the rapid advancement of technology lead to the depletion of renewable energy sources, global warming, and an energy crisis. The energy crisis and climate change, which have recently become major concerns for many countries, are foreseen to cause climatic and societal problems such as the depletion of natural resources, an increase in natural disasters, and water scarcity. Therefore, most countries, especially in Europe, have made decisions in various agreements and conferences to control and reduce energy consumption in order to overcome the energy crisis (Ortega Pastor et al., 2024). Some of these decisions include various restrictions related to the construction sector, which accounts for approximately 40% of global energy consumption, according to global data (International Energy Agency, 2023; European Commission, 2021). To reduce the energy used in buildings, it has been suggested—and incorporated into regulations—that climate-responsive, energy-efficient building designs and innovative design approaches be utilized.

According to the 2024 reports of the International Energy Agency (IEA), a significant portion of the energy consumed in buildings stems from heating and cooling systems. The energy spent to ensure indoor comfort in buildings constitutes approximately 50–70% of total consumption. Additionally, 30% of the total energy used in buildings contributes to global final energy consumption, which in turn accounts for 26% of energy-related global emissions. Cooling systems, in particular, are causing a significant increase in electricity demand due to rising income levels and climate change, especially in developing countries. The IEA projects that by 2030, energy consumption from air conditioning and appliances in buildings will increase by 35% (IEA, 2024; IIR, 2024). For this reason, architects, due to their responsibilities toward the physical environment, are expected to evaluate the energy use of the buildings they design and to adopt climate-focused design approaches. Within the scope of this study, in consideration of the projected increase in global temperatures in the future, the importance of shading elements that contribute to building energy efficiency and reduce the need for cooling energy will be explained and evaluated with references from the literature to support their development.

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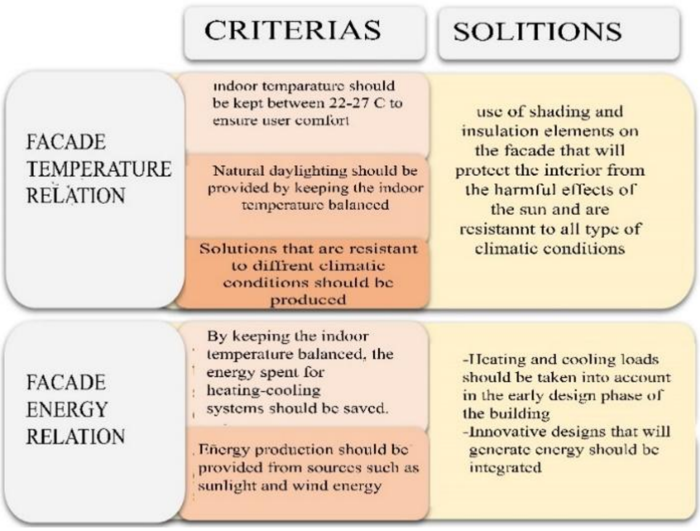


Fig. 1. The Relationship Between Façade, Temperature, and Energy, and Its Solutions
(Adapted from Esgil, M., and Yamaçlı, R., 2023)

The effective control of heating and cooling energy in buildings largely depends on the performance of the building envelope (walls, roof, windows, and floors), as it is in direct contact with the external environment. The purpose of the building envelope is to act as a barrier between the indoor and outdoor environments, ensuring indoor comfort (Gür, 2007). A well-designed building envelope significantly reduces energy demand by minimizing the effects of external conditions on the interior. Heat loss and gain, insulation quality, air tightness level, and the effectiveness of window and shading systems are directly affected by factors such as these, which in turn reduces the load on HVAC systems. Therefore, the energy-efficient design of the building facade is very important to achieve low carbon targets and sustainable building strategies (Ascione et al., 2016). In conclusion, to understand the importance of the building facade, which directly affects indoor comfort in a sustainable environment, it is necessary to understand how temperature and energy are related to the facade. Fig. 1 explains the relationships between the building envelope, energy, and temperature.

The building envelope emphasizes the importance of comprehensively considering thermal and visual comfort between energy and temperature.As a result, the design of the building envelope is extremely important in terms of contributing to the sustainability of both the user and the physical environment. Rising global temperatures due to climate change have increased the need for cooling energy use of buildings, especially in warmer climate zones. It shows, trategies to improve energy efficiency in the building sector need to be revisited and improved. Therefore, the effective use of shading materials within passive design strategies plays an important role in modern building design in terms of both energy savings and thermal comfort. Controlled management of solar radiation not only reduces dependence on mechanical systems, but also reduces carbon emissions and reduces the need for cooling energy of buildings (Olgyay, 2015).

According to these data, researchers have investigated the design of shading elements to reduce the cooling energy demand of buildings, especially those located in hot climate zones. This study reviews and evaluates recent research on methods tools for shading element design performance parameters.

2. Design Parameters of Shading Elements in Hot Climate Regions

Shading element design can take form according to design parameters such as the function of the building, its location, climatic conditions, design expectations such as lighting, heating and cooling for the needs. For this reason, in order to design a shading element, the purpose should be clearly defined before the study. The performance criteria of a shading element design are generally shown in Table.1. as building energy performance, thermal comfort, visual comfort, lifetime and cost, aesthetic requirements (Özyer, 2017, Koç, 2019, Erkan 2024). Since this study evaluates shading elements in terms of building energy use and indoor comfort, it will focus on building energy performance, thermal comfort and visual comfort parameters.

Table 1. Expected Performance Criteria of Shading Elements (Erkan, 2024)

Building Energy Performance	Cooling Energy Consumption Heating Energy Consumption Lighting Energy Consumption Ventilation Energy Domestic hot water systems
Thermal Comfort	Temperature Humidity Air Velocity
Visual Comfort	Glare Control Adequate Illumination Level Uniform Daylight Distribution
Service Life And Cost	Low Initial Construction Cost Long Service Life Material Recyclability High Durability (Minimum Maintenance And Repair Needs)
Aesthetic Requirements	Visual Connection With The Outdoor Environment Privacy Contribution To The Building Façade

According to the factors shown in the table, cooling, heating, lighting, energy consumption within the building energy performance parameter, temperature, humidity, glare control, adequate illumination level within the thermal comfort parameter, homogeneous daylight distribution within the visual comfort parameter, interior lighting according to the data obtained from the literature, energies criteria have played an important role in the selection of studies to be evaluated within the scope of this study as they directly affect user comfort and building energy consumption.

When determining appropriate parameters for shading element design, sometimes favorable conditions can turn unfavorable.For example, shading elements block solar radiation from entering indoor spaces, especially during the summer months.This results in less energy consumption for cooling.However, they may consume more heating energy than heating energy because they can block useful solar radiation in the winter months.Similarly, shading elements can consume more electricity by blocking sunlight.This can lead to more energy waste in efforts to reduce the building's energy consumption.As a result, when designing shading, it is important to consider the connection between lighting, heating, and cooling (Özyer, 2017).

To design shading elements, it is essential to first know the desired comfort level in indoor spaces.The presence of daylight should be well defined for indoor comfort.Therefore, it is necessary to examine the Daylight Assessment Criteria to evaluate the performance of the shading element during the preliminary design phase. Daylight availability (daylight availability-DA) is a fundamental metric that measures the adequacy of natural lighting in the interior spaces of a building.There are two main classes of this evaluation: static and dynamic.Using local climate data, dynamic or climate-based metrics evaluate annual performance.In this case, Daylight Autonomy (DA) refers to the percentage of time a space is illuminated solely by daylight. Daylight Illuminance (UDI) categorizes lighting levels in the range of 100 to 2000 lux as useful.

Additionally, a metric known as Spatial Daylight Autonomy (sDA) measures whether a specific area is adequately illuminated by daylight.This measurement indicates whether a certain percentage of the floor area exceeds a specific lighting level (e.g., 300 lux) during the analysis period (Illuminating Engineering Society, 2012).Direct sunlight exposure (ASE) is used to evaluate visual comfort (Yıldırım et al., 2024; Meek & Van Den Wymelenberg 2014).

Other metrics used for daylight visual comfort were created to measure the glare problem. Daylight Glare Probability (DGP) is a metric that estimates the probability of a user being affected by glare and is based on subjective experience (Wienold & Christoffersen, 2006). This metric is used to assess visual comfort and takes into account the level of brightness, the position of light sources and visual contrast. Glare is considered to be very uncomfortable if the DGP value is 45% and above, uncomfortable in the range of 40-45%, perceptible in the range of 35-40%, and imperceptible below 35% (Wienold, 2007)(Fig.2). These criteria play a significant role particularly within the scope of sustainable building certification systems (such as LEED v4, BREEAM, CASBEE, etc.) and lighting comfort, in ensuring visual comfort in indoor spaces and optimizing energy performance.

Glare	Daylight
Daylight Glare Index (DGI)	Daylight Autonomy (DA)
Visual Comfort Probability (VCP)	Continuous Daylight Autonomy
British Glare index (BGI or BRS)	Useful Daylight Illuminance (UDI)
Daylight Glare Probability (DGP)	Spatial Daylight Autonomy (SDA)
Simplified discomfort glare probability (DGPs)	Annual Sunlight Exposure (ASE)
CIE Glare Index (CGI)	Daylight Factor (DF)
Unified Glare Rating (UGR)	Mean Illuminance (MI)
j- Index	Vertical eye illuminance (E_v)

Fig. 2. Parameters of Evulate Glare and Dayligthing (Valtibar etal., 2018)

A sustainability-focused design is essential to achieve an ideal balance between natural lighting and thermal comfort in indoor environments. After determining the dynamic daylight evaluation metrics aligned with the intended purpose, it is necessary to decide on the method by which these metrics will be measured. From past to present, the direction and intensity of solar radiation falling on the shading element, and the location of the design on the façade, involve many variables. To achieve this goal, various daylight measurement methods have been used over time, including solar path analysis, light and thermal impact assessments, computer-aided simulations, physical modeling, heliodon testing, and on-site measurements (Yıldırım et al., 2024).

Table 2. Methods for Measuring Natural Daylight Usable in the Design of Shading Elements (Yıldırım et al., 2024)

In the Design Process		In the Usage Process
Pre-Design Phase	Detailed Design Phase	On-Site Physical Measurement High Dynamic Range Imaging
- Sun Path Analysis - Mass Modeling - Shading Calculation	- Computer Simulation - Heliodon Analysis with Physical Scale Model	

According to the information obtained from the literature, solar path analysis and computer simulations are the most commonly used techniques in this study. Solar path analysis allows designers to measure the angle and intensity of sunlight reaching a building at a specific location throughout the year, enabling them to monitor how solar radiation affects the design process. Polar or cylindrical projections show the sun's position in the sky. These diagrams show the trajectory of the sun in two dimensions, both over the course of a day and a year. This helps architects study the effects of the sun (Bodart & Cauwerts, 2017) (Fig. 3).

Computer simulations are an effective tool for analyzing a space's daylight performance under different sky conditions throughout the year. The geographical location of the space, CIE sky models, and specific date-time data are used to conduct these simulations. After determining the illumination levels on the working plane, static metrics such as Daylight Factor (DF) and dynamic metrics such as Useful Daylight Illuminance (UDI), Daylight Glare Probability (DGP), and Daylight Autonomy (DA) are evaluated.Moreover, it has been observed that climate-based dynamic measurement methods are more widely used in recent research (Oral, 2023).

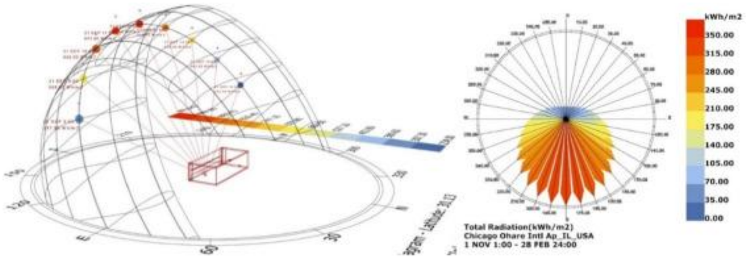


Fig.3 An Example of Solar Path Analysis (Eltaweel, A., & Yuehong, S. U., 2017)

In order for the shading element form to be created, after determining the performance parameter, daylight evaluation criteria, and daylight performance measurement method, it is necessary to go through the decision-making stage to determine the form, orientation, and movement of the shading element. The type, size, and inclination of shading elements play an important role in controlling solar radiation; fixed and movable systems offer different advantages (Tzempelikos, A., & Athienitis, A. K., 2007). Shading elements are divided into two categories according to their form: fixed and movable. Due to the variability of the parameters effective in the design of shading elements throughout the year, month, and day, maximum benefit can be achieved by designing the elements to be movable according to the purpose and desired evaluation metrics. Movable shading elements offer the possibility of optimizing both cooling and heating energy consumption by opening and closing according to the changing needs throughout the year. In addition, while fixed horizontal shading elements block solar radiation coming at steep angles more effectively than vertical shading elements, lattice-type shading systems, which are a combination of both types, provide higher efficiency in reducing cooling energy consumption by blocking low-angle radiation at different times of the day (Koç, 2019). In Table 3, shading elements are classified according to their forms.

Table 3. Classification of Shading Elements by Form (Özyer, 2017)

Classification by Form			
Fixed Shading Elements		**Movable Shading Elements**	
Horizontal Shading Elements	Vertical Shading Elements	Horizontal Shading Elements	Vertical Shading Elements
Hybrid (Louver-Box) Shading Elements	Parallel Plate Shading Elements	Awning Shading Elements	Venetian Blind Shading Elements
		Kinetic Shading Elements	

Among movable shading elements, kinetic shading elements are designs that have the ability to change certain functions, properties, or behaviors in response to changing performance requirements and variable boundary conditions over time, and this flexibility is used with the aim of continuously improving overall building performance. Kinetic shading elements include building components that differ in terms of materials, components, and systems. They have the potential to reduce energy consumption while enhancing indoor comfort (Attia et al., 2020). Therefore, when designed in conjunction with today's design technologies, they are more efficient than other fixed and movable shading elements, as they provide ease of design and enable monitoring of the desired comfort level.

3. Kinetic Shading Element Design

Kinetic shading elements are systems that can automatically change their shapes, orientations, openings, and positions in facade design in response to environmental variables such as temperature, humidity, and wind. The ideal lighting level and thermal comfort for indoor spaces are achieved by these systems by controlling thermal gains and making the best use of daylight. Kinetic facades enhance indoor comfort and increase the energy efficiency of building designs because they operate in an environmentally conscious manner (Güncü, A. and Kurunç, A., 2013).Today, in recent studies conducted with technological developments, parametric design is used when designing kinetic shading elements. Parametric design allows for easy modification of a large number of parameters in a digital environment and simultaneous testing of elements with simulation tools (Razzaghmanesh, 2015). Therefore, it is important to use parametric design tools in the design of kinetic shading elements to respond to today's variable weather conditions.

Parametric design allows different ideas to be developed quickly and effectively during the design and production stages. This method gives the designer the opportunity to evaluate different scenarios and manage decision-making processes flexibly. Parametric modeling enables the design to be continuously reviewed, evaluated and updated. This flexibility makes it easier to find various design options (Engin, 2022).

This research categorizes two main parametric design processes known as genetic algorithm-based systems and rule-based design systems. Rule-based systems, also called shape grammar-based design systems, guide the design process through predefined geometric and logical rules. Creative solutions such as origami patterns or traditional or cultural motifs can be used in trial-and-error based evaluation systems (Belek and Yamaç 2023). Genetic algorithms can develop and optimize various design options using evolutionary approaches inspired by nature. Efforts to find the best design are related to gene transfer, mutation rules, and reproduction.Variation generation has the ability to solve complex surfaces and geometric challenges (Radwan, Osama, 2016). By using one of these two methods, designers can manage the process dynamically and flexibly and define a specific target parameter (Alafandy & Kazzaz, 2018).

Compared to traditional architectural modeling, parametric design provides a faster and more efficient process. Changes made in traditional design often take a long time and require remodelling, but in parametric design, the design can be easily modified. This method defines the relationships between elements, and these relationships shape the design. Parametric tools provide flexible and adaptive solutions, especially for complex facade issues in architecture. Hybrid platforms that combine features such as modeling, simulation, and evaluation are typically these types of tools. It is very important to choose the right method or tools to achieve the correct design outcome. Nowadays, parametric design tools are used to easily design the variables of kinetic shading elements (Panya et al., 2020)(Fig.4).

	Geometry and Data Modeling	Energy and Thermal Simulation, Climate Analysis	Daylighting Simulation	Computational Fluid Dynamic Simulation
Main Scope	Create geometrical and data model that support simulation	Predict the impact of architectural design in energy consumption and emissions	Anticipate natural light quality and visual comfort as a function of a space's geometry and material surfaces	Model airflows inside and outside the buildings, predict comfort
Concept Design	Rhino, Sketchup, Vasari	Ecotect Sun Tool, Ecotect, Vasari(Beta), Climate Consultant, EcoDesigner, ComFen	Ecotect, Velux Daylighting Visualizer, Radiance, DIVA	Vasari Wind Tunnel(Beta), Design Builder CFD
Design Development	Revit, Archicad	OpenStudio, EnergyPlus, DesignBuilder, IES-VE, eQuest, TRNSYS	3Ds Max, Radiance, Daysim, DIVA	Fluent, Virtual Wind
Parametric Design	Grasshopper, Dynamo	JePlus, JePlus EA	Grasshopper and various plug-ins	

Fig.4 Parametric Design Tools and Their Functions in Architecture (Panya et al., 2020)

For example, the Grasshopper plugin designed for Rhinoceros software, especially when used with the Ladybug tool, is one of the most frequently used tools in the field of parametric design. Grasshopper is an algorithmic modeling platform that structures the design process through a network and graphically represents the relationships between dependent parameters. This structure allows designers to monitor the parametric relationship network they create and take the steps they desire. Simulation-based tools accelerate the design process and enable the evaluation of system performance and the comparative analysis of various designs. Therefore, solutions with the best performance criteria can be easily obtained. However, there is no single tool that can be applied to every design problem. As a result, the context of the design, the expected performance output, and user requirements should determine the appropriate software and simulation tools. In this context, the tools used in the parametric design process are shown in Fig.5 the example flowchart below.

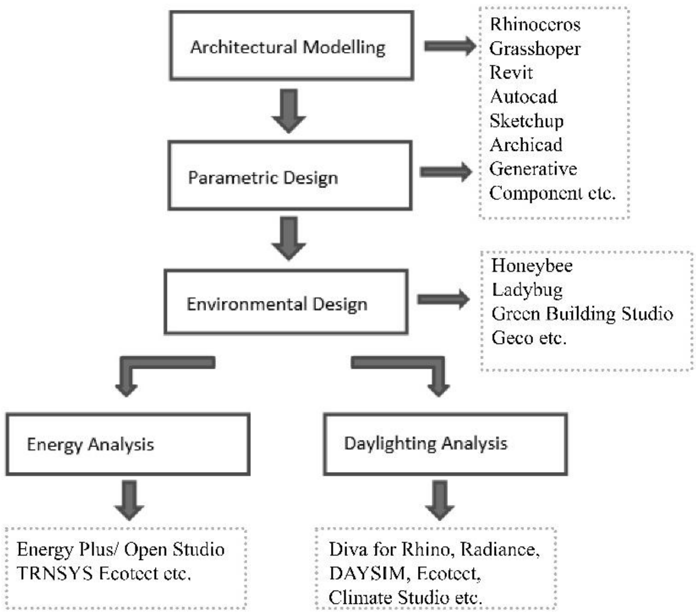


Fig.5 Systematic Diagram of Tools Used in the Parametric Design Process (Adapted from Seyrek et al., 2021)

Studies in the literature reveal that the design of kinetic shading elements plays a critical role in solutions aimed at reducing the cooling energy demand of building envelopes, especially in hot climate regions. In this context, daylight metrics, temporal variables, and user comfort parameters should be evaluated together during the design process. Due to the multivariable nature of the issue, it has been demonstrated that the use of parametric modeling and simulation-based methods is necessary in the design of kinetic shading elements.

The optimization process for determining the performance of kinetic facade systems includes a performance-oriented phase that evaluates the parametric model-based design under climatic conditions. The design models developed in this process are analyzed using climate-based simulation tools such as Ladybug, HoneyBee, EnergyPlus, Radiance, Daysim, and ClimateStudio (Panya et al., 2020; Seyrek et al., 2021). Based on the obtained data, variations are generated through different configurations of the kinetic facade system, and these variations are comparatively evaluated within the scope of the performance-based optimization process. In this way, through the holistic interpretation of simulation and analysis outputs, the extent to which the design criteria contribute to the targeted functionality and energy efficiency level is determined. Therefore, parametric design methods and tools are the most beneficial design approach in the design of shading elements intended to reduce cooling energy demand. Within the scope of this study, recent kinetic shading element studies have been evaluated in terms of expected performance criteria, forms, dependent and independent variables affecting the design, and the optimization references targeted for the efficiency of these variables.

4. Material and Metot

In this study, kinetic shading element studies developed in recent years with different performance expectations were compiled using data obtained from the literature. These studies were examined in terms of their design purposes, parametric design tools and methods, dependent and independent variables, optimization methods, and references. The responses of the variables dependent on the design objectives to the independent variables affecting the form were observed, and whether a relationship existed between them was evaluated. For example, in the study by Kim, D. H., et al., the impact of movable shading systems to optimize daylight was investigated. Shading elements were evaluated in terms of daylight performance metrics such as SDA, ASE, UDI, and LUX, considering independent variables like geometric types, dimensions, rotation angles, opening and closing rates, and presence or absence. The data-based method proposed using a Genetic Optimization algorithm produced results that met LEED v4.1 standards, indicating the successful development of the kinetic shading element. The values analyzed in the table were evaluated specifically for each study, and their explanations are noted below the Table.4.

Table 4. Kinetic Shading Element Studies From Literature

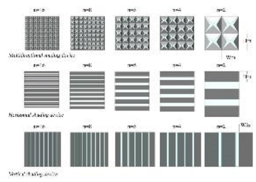
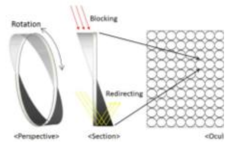
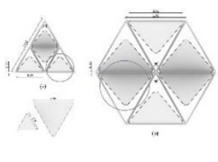
Reference (Author, Year)	Purpose	Form	Independent Variable(s)	Dependent Variable(s)	Optimization Method - Reference	Images Of Study
Kim, D. H., et al., 2024	VC	Vertical Horizontal Hybrid Spatial	T SOD SEM (R, SL, FL) SE SG UL	Sda ASE UDI LUX	Genetik Optimizasyon Galapagos - Leed V4	
Im, O. K., et al., 2019	TC VC	Hybrid Spatial	T SEM (R)	EUI Dav SI	Min-Max Optimization - Leedv4 ASHRAE IES	
Kızılörenli, E., & Maden, F. , 2023	TC VC	Hybrid Spatial	T SOD SEM (R) SE SG	ASE Sda UDI DGP	Simulation - based Optimization- REİNHART IES	

Table 4. continued

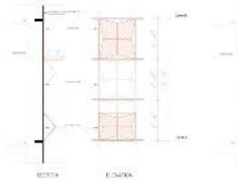
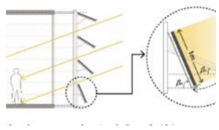
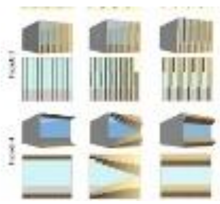
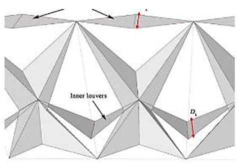
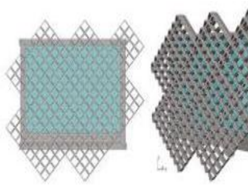
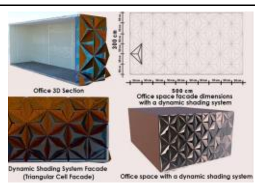
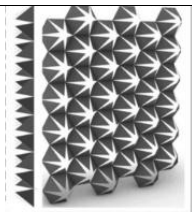
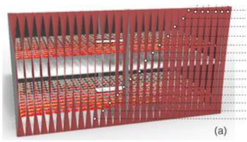
Akimov, L., et al.,2023	ES VC	Hybrid Spatial	SS DSF SOD SEM (R) SG	UDI DGP LUX Da	Genetic Algorithms Multi-Objective Optimization (MOO) - CBDM	
Sheikh, WT & Asghar, Q. ,2019	ES VC	Hybrid Spatial Biomimicy	SS FL SG SD	DF EUI LUX	Simulation-based optimization - CISBE	
Choi, H. S., 2023	ES TC EG	Horizantal Louvers PV Panel	T BL SEM(R) SPP SSE	SDA EUI SR PMV	Simulation-based optimization	
Toodekharman, et al., 2023	VC	Hybrid	T SOD SE SEM (R, FL) SG STT UL WWR	ASE SDA DGI DGP DA	Simulation-based optimization - LEED V4	
Elghandour, et al. 2016	VC	Hybrid	SOD STT SD SS	ASE SDA DGP Da	Genetic Algorithms+ Exhaustive Search - LEED V4 IES	
Hassan, A., et al., 2017	ES VC TC	Hybrid	SEM (R) SE SD SS	ASE Sda EUI Dav Da	Adaptive Parametric Algorithm (APA) + GA - LEED V4 IES ASHRAE 90.1-2007	
Özdemir, H., & Çakmak, BY, 2022	VC	Hybrid Hexagonal Moduler cell	T SEM(FL) SE	ASE Sda UDI DGP	Simulation-based optimization - LEED V.4	

Table 4. continued

Ashraf, N., & Abdin, A. R. ,2024	ES TC	Hybrid Biomimicy	SOD SEM(FL) SE	SDA EUI	Muliobjection Optimization - LEED V.4	
Sankaewthon g, S. et al., 2022	ES VC TC	Vertical Spatial Biomimicy	T SOD SEM(R) SE SG	GF-DF ASE SDA LUX	Genetic Algorithms + Simulation-based optimization - LEED V.4 EN 12464	

T: Time, BL: Building Location, SOD: Shading Element Opening/Closing State, SEM: Shading Element Movement (R: Rotation, SL: Sliding, FL: Folding), STT: Shading Element Material Transmittance, SSE: Size Of Shading Element, SPP: Shading Element Material Properties (C: Color, N: Number), SD: Shading Element Depth, SS: Shading Element Size, SE: Shading Element Existence, SG: Shading Element Geometry, FL: Façade Location, DSF: Distance from Structure Façade, UL: User Location, VC: Visual Comfort, TC: Thermal Comfort, ES: Energy Saving, EG: Energy Gain

According to the table, it is observed that the kinetic shading element studies reviewed from the literature have utilized parametric design tools for real-time simulations based on the expected performance, and have successfully provided benefits in accordance with relevant performance optimization references. Moreover, in recent shading element design studies, it is seen that studies with different performance goals employed different independent variables, while those with common objectives tended to use shared independent variables in their design processes. This suggests that a useful relationship can be established between dependent and independent variables.From the literature, if more studies are added to the table and common goals are found to be linked to similar independent variables, it may be possible to develop multiple methods for designing kinetic shading elements based on data gathered from the literature. However, it is considered that more studies need to be evaluated in order to establish these methods.

5.Conclusion

Kinetic shading elements have the ability to instantly respond to climatic conditions and user demands. Within the scope of this study, in order to reduce the cooling energy demand of buildings in hot climates (which is considered the main problem) and to bring indoor comfort to the optimum level in line with the desired goals, kinetic shading elements must be designed by considering multiple parameters. In this study, the reviewed recent examples are responsive kinetic façade designs that provide dynamic responses to environmental effects, adapt to varying environmental conditions, and thus increase indoor comfort while reducing energy consumption. These design approaches play a significant role in enhancing energy efficiency and advancing sustainable architecture. Based on the examples examined and the data obtained from the literature within this study, the necessary parameters for designing a shading element have been compiled and presented in the table below.

Table 5. Required Parameters for Kinetic Shading Element Design

Factors Directly Influencing The **Design** Of The **Shading Element**		**Environmental Properties Independent** Of The **Shading Element**	
Form - Vertical Louver -Horizontal Louver - Hybrid Design -Space Frame, Etc.	Design Performance Goal - Visual Comfort - Thermal Comfort - Energy Saving, Etc.	Building Location And Climate Characteristics	- Building Type (Office, School, Hospital, Etc.) - Number Of Occupants
Parametric Design Method And Tool - Shape Grammar-Based Design - Genetic Algorithm-Based Design	Daylight Performance Criteria And Method - ASE - Sda - DGP - EUI, Etc.	Position Of The Shading Element On The Building Façade (North, South etc.)	- User's Position İnside The Space - HVAC System - Window-To-Wall Ratio (WWR)

Table 5. continued

Movement Of The Shading Element - Rotation - Folding - Sliding, Etc.	**Material Properties** **- Material (Wood, Metal, Plastic, Etc.)** **- Transparency Ratio** **- Color** **- Reflectance Ratio** **- Quantity**	**- Material Properties İn The Environment (İnterior-Exterior Wall, Floor, Ceiling)** **- Thickness** **- Conductivity** **- Thermal Absorptivity** **- U, R Values** **- Reflectance Value, Etc.**
Optimization Method And Tool - Pareto Front - NSGA II, Etc. Simulation Tools (Galapagos, Honeybee, Etc.)	- Distance From The Building Façade - Shading Element Depth - Scale (Size) Of The Element - If Louvered, Open-Close Ratios - Inclination Angles Of The Shading Element, Etc.	- Outdoor Relative Humidity - If Present, Artificial Lighting in The İnterior - Solar Radiation

The Table 5 above serves as a roadmap for researchers who wants to design kinetic shading elements and need the necessary parameters. Since the factors listed in the table are based on research and data from the literature, studies that were not considered and the factors of specific designs have not been included; therefore, additions can be made to the factors in the table. However, in general, these are the relevant parameters. As technological developments advance and different design methods emerge, the table will need to be updated. The study shows that the design of kinetic shading elements makes a significant contribution in the context of the building sector, which is currently responsible for a share of energy consumption, and is expected to become even more important in the coming years to help mitigate global climate crises. The study has revealed the importance of well-designed kinetic shading elements in reducing the energy buildings spend on cooling loads.

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Investigation of the steel material used in the structural system of alvar aalto's buildings: the case of villa mairea

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Abstract. Steel is an important building material in the field of architecture and has many advantages. It is durable, lightweight, fast to produce, reusable and long-lasting. Most importantly, it is cheap and can be used in large shapes. These extreme features led Alvar Aalto to turn to steel. Alvar Aalto is one of the most important modernist architects of the 20th century. He made great contributions to Finnish architecture. It generally deals with the use of natural materials, organic functions, and human-centered designs. However, as Aalto's career progressed and he explored new materials and technologies, he began to incorporate steel into his designs. It has built composite buildings with steel and other building materials in its structures. Alvar Aalto's use of steel combined with other materials allowed him to create balanced and aesthetic projects. He was able to use steel successfully in every aspect of his designs, which he generally used to ensure the continuity of glass and to design wide openings. From the smallest to the largest structure, the use of steel is an ongoing practice. The steel he uses in every field can be seen sometimes in his accessories and sometimes in his furniture. Although the steels used in their structures are not clearly visible, it can be understood when looking at the drawing techniques in the project. In the case of Villa Mairea, he used steel without hiding it and integrated it with other building materials. Among the features of steel material in Villa Mairea, especially its structural feature has been utilized.

Keywords: Alvar Aalto; Steel; Structural System; Building Material; Villa Mairea

1. Introduction

In the first half of the 20th century, steel emerged as a transformative material in architectural structural systems. Modernist pioneers such as Le Corbusier and Mies van der Rohe employed steel not only as a technical innovation but also as a medium for aesthetic expression. However, Alvar Aalto developed a distinctive approach that sought to integrate modern technology with the humanistic and cultural dimensions of architectural design (Frampton, 1995; Pelkonen, 2009).

Villa Mairea serves as a compelling example of Aalto's unique interpretation of steel usage. The building is noteworthy not only for its incorporation of modern materials, but also for the way these materials are transformed to evoke a humane and nature-oriented architectural atmosphere (Schildt, 1994; Siren, 2013).

2. Villa Mairea (1938-1941)

Villa Mairea was commissioned by Harry and Maire Gullichsen, leading figures of the A. Ahlström company, and constructed within the Noormarkku ironworks estate (Alvar Aalto Foundation, n.d.).

The exterior elevations feature a combination of materials: segments of untreated Finnish pine and timber, alongside fine stone slabs and roughcast plaster. At the main entrance, a row of columns composed of unstripped saplings supports a free-form canopy. From the entrance hall, a short flight of steps leads to the living room, where an irregularly shaped staircase encircled by asymmetrical wooden posts ascends to the upper floor (Fig. 1). A portion of the outer wall is designed with a sliding system that allows for the complete opening of the house to the garden.

The dining room window faces an internal courtyard, while a rear door opens to a covered passage leading to the sauna. The kitchens are adjacent to the dining room, and behind them are rooms designated for the household staff. A secondary staircase connects the kitchen to the children's playroom, the breakfast room, and the guest wing. The upper floor also includes the family bedrooms and Maire Gullichsen's painting studio (Alvar Aalto Foundation, n.d.).

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Fig. 1. A photograph illustrating the interior of Villa Mairea, featuring the steel columns and the wooden staircase detail.

3. The Role of Steel in the Structural System of Villa Mairea

The structural system of Villa Mairea is hybrid in nature, incorporating reinforced concrete elements, steel columns, and wooden beams. This combination ensures both structural stability and spatial flexibility (Docomomo Suomi/Finland, n.d.).

Although wood dominates the material palette, steel columns are visibly present and architecturally significant. As illustrated in the floor plan (Fig. 1), the steel elements are distributed throughout the structure, exemplifying a dispersed load-bearing system (AACDAS, 2015).

In the main hall and entrance area, the circular-section steel columns enable broader spans and a more fluid spatial configuration (Poole, 2017).

Rather than being arranged in a strict grid, these columns are positioned in a seemingly random rhythm reminiscent of trees in a natural forest. This strategy transforms the structural system into an integral component not only of the building's physical framework, but also of its spatial and emotional experience (Siren, 2013).

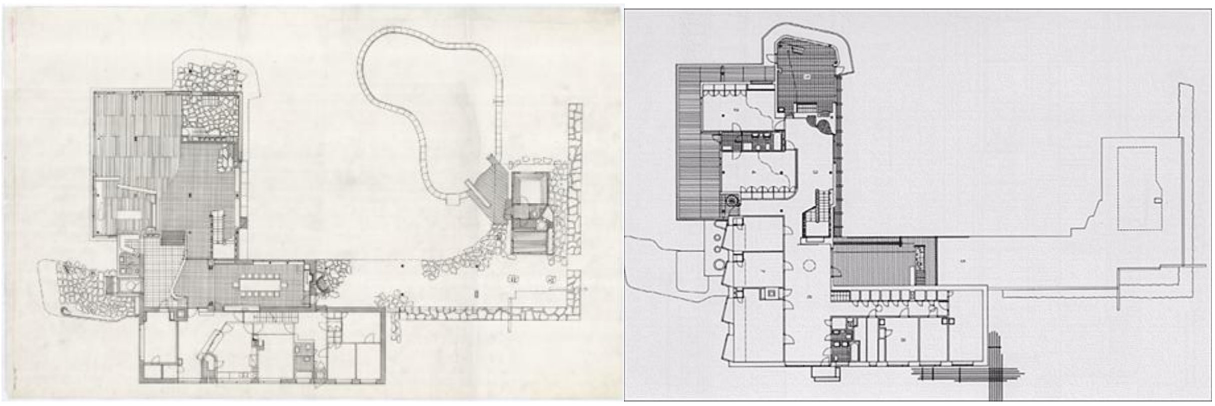

Fig. 2. A photograph showing the ground floor and first floor plans of Villa Mairea.

The steel columns have been treated with various cladding techniques; some are coated with glossy black paint, while others are wrapped in rattan or birch bark strips (Fig. 3) (Schildt, 1998). Through these interventions, the columns acquire a visual and tactile resemblance to tree trunks in nature, effectively softening the industrial character of the steel.

Fig. 3. A photograph depicting the columns in Villa Mairea that are painted in glossy black and wrapped with rattan or birch bark strips.

Steel also plays a crucial role in the main staircase system. The steel beams that serve as the primary load-bearing elements are concealed within wooden cladding, thereby ensuring structural integrity while maintaining a sense of visual lightness and natural material expression (Boelkins, 2017). The structural framework of the staircase is resolved through steel without being exposed, allowing the supporting elements to fulfill their function without imposing a visible presence on the user (Fig. 4).

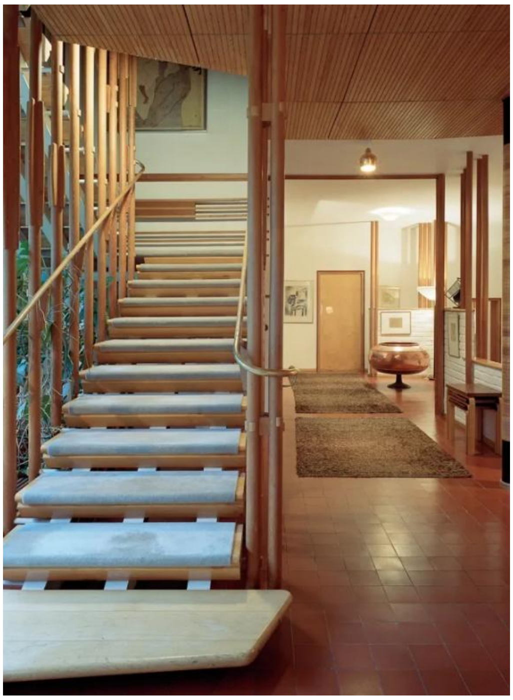

Fig. 4. A photograph of the main staircase of Villa Mairea.

The canopy structure located at the entrance is supported by slender, white-painted steel columns (Fig. 5). These columns are designed with minimal cross-sections, relying on the inherent strength of steel for load transfer. The curvilinear reinforced concrete canopy they support serves not only as a protective element but also as a symbolic gesture of welcome at the threshold (Angela Adams, n.d.). The entrance door itself is clad with vertical wooden slats and integrated into a steel frame for structural support and visual coherence.

Fig. 5. A photograph of the entrance canopy of Villa Mairea, supported by white-painted steel columns.

Steel also plays a significant structural role in the upper-floor terrace located at the rear façade of the building. A slender steel beam supports the roof covering, transferring its load to a concrete beam, which in turn conveys the load to the ground via a steel column. This system demonstrates the functional contribution of steel in terms of spanning capacity as well as maintaining spatial continuity within the architectural composition (AACDAS, 2015).

In the examples discussed above, steel performs critical tasks from a building physics perspective while simultaneously enhancing the aesthetic and experiential qualities of the structure through its integration with other materials.

Fig. 6. A photograph of the steel column located on the terrace of Villa Mairea.

4. The Use of Steel, Wood, and Concrete

In Villa Mairea, Aalto never employed steel as an isolated material. Rather, it is consistently placed in dialogue with local and natural materials such as wood, stone, and brick (Pelkonen, 2009).

For instance, while the canopy at the entrance is supported by white-painted steel columns, the adjacent sauna area draws on traditional Finnish architecture by utilizing roughly hewn timber logs as load-bearing elements (Angela Adams, n.d.). This juxtaposition highlights the building's technical and cultural diversity.

A similar approach is observed on the upper terrace. In the roof system, wooden cladding is supported by steel beams, which in turn are anchored to reinforced concrete load-bearing elements. This configuration ensures a balanced distribution of structural loads and contributes to architectural coherence (AACDAS, 2015).

In Villa Mairea, steel is not merely employed for structural necessity; it is seamlessly integrated with other surfaces and formal elements to enrich the spatial atmosphere (Poole, 2017; Siren, 2013). This demonstrates that steel is regarded not only as a technical component but also as an experiential element within the design process.

5. Comparative Analysis: Villa Mairea and Contemporary Modernist Buildings

The significance of steel in Villa Mairea becomes clearer when compared to contemporary modernist works. In Le Corbusier's Villa Savoye (1931) or Mies van der Rohe's Barcelona Pavilion (1929), steel and reinforced concrete are openly expressed, with the structural system forming a direct extension of architectural aesthetics

(Frampton, 1995). In these examples, steel columns are typically left exposed, allowing the structural reality of the building to align with its architectural language.

In contrast, Alvar Aalto's approach in Villa Mairea reflects a more holistic and intuitive design philosophy. Steel is treated not merely as a technical material but as an element intertwined with nature, human experience, and local culture (Pelkonen, 2009). The steel columns in Villa Mairea are designed not only as load-bearing components but also as elements that evoke the impression of a forested landscape within the interior space (Siren, 2013).

Unlike Mies van der Rohe's minimalism, Aalto enriches the steel elements through material layering. For example, in Villa Mairea, steel columns are wrapped with rattan or birch strips, enabling them to blend with the natural environment. Thus, they become not only structural supports but also aesthetic components of the spatial narrative (Schildt, 1998).

In Aalto's design, steel is not arranged in a rigid grid system but rather dispersed irregularly, mimicking the random distribution of trees in nature. This approach introduces a spatial rhythm that is both visual and emotional (Poole, 2017). In doing so, it presents an organic and human-centered design language that contrasts sharply with the systematic and repetitive logic of high modernism.

Ultimately, Aalto's use of steel in Villa Mairea deviates from the strictly technical approaches of his contemporaries. Here, steel is not just a structural material but a creative and atmospheric element within the architectural composition.

6. The Use of Steel in Aalto's Later Works

Villa Mairea can be regarded as one of the initial milestones in Alvar Aalto's architectural engagement with steel. Following this project, Aalto continued to employ steel in both structural and architectural roles across various scales and building typologies. This continuity indicates that steel became a permanent part of his design vocabulary—not merely as a material, but as a conceptual tool.

The Finnish Pavilion for the 1939 New York World's Fair stands as another notable example of Aalto's approach to steel. Constructed using a lightweight steel frame, the pavilion not only achieved structural efficiency but also allowed for large interior spans suited to exhibition functions (Weston, 1995). The transference of Villa Mairea's design logic to this context further reinforces steel's role in Aalto's evolving architectural language.

Similarly, the Seinäjoki Civic Centre (1958–1968) exemplifies the continuity of this approach. In this complex, steel and reinforced concrete are used in tandem—particularly in large-span public spaces where steel becomes an integral component of the structural system (Weston, 1995). This reveals how Aalto's method of material hybridity extended into larger-scale public architecture.

Aalto's evolving use of steel provides a compelling example of how the relationship between material and space can be reimagined in architecture. The principles developed in Villa Mairea were carried forward and further elaborated in his later works, both technically and aesthetically.

7. Conclusions

Alvar Aalto's treatment of steel in Villa Mairea stands as a significant example in modern architectural history, not only from a technical standpoint but also as a design philosophy. He used steel not merely as a load-bearing component but as an integral part of the architectural narrative. Combined with reinforced concrete and timber, steel contributed to a hybrid structural system that enabled wide spans and supported spatial continuity.

The steel columns in Villa Mairea functioned not only structurally but also compositionally—evoking a forest-like ambiance in the interior. Through surface treatments such as paint, rattan wrapping, and birch cladding, the industrial identity of steel was softened to create a more tactile and sensory aesthetic. These choices reflect Aalto's commitment to integrating technical materials into a human-centered architectural language.

This distinctive approach continued in his subsequent works. In both the Finnish Pavilion (1939) and the Seinäjoki Civic Centre (1958–1968), steel was employed to achieve structural spans, spatial flexibility, and a sense of architectural lightness. Aalto's consistent use of steel across different scales illustrates how it can function not only within an engineering context but also as a cultural and aesthetic medium.

In conclusion, Villa Mairea exemplifies a holistic architectural approach in which steel is considered not just for its structural capacity but for its symbolic, spatial, and experiential dimensions. Through this work, Aalto developed a unique interpretation of steel that foregrounds the material's multifaceted role in architectural design—offering a lasting source of inspiration for contemporary practice.

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Cool roofs: development and characterization of reflective tile coatings to mitigate urban heat island effect

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Abstract. Most of the thermal discomfort in the Mediterranean urban areas arises from the Urban Heat Island (UHI) effect. As the sun shines almost vertically down on top of the cities, geometrically speaking, the roofs and open terraces are the areas that are exposed to direct solar radiation during the day. If minimization of UHI is the concern, the solution is mostly in the roof tiles and floor tiles covering terraces. If some of this solar radiation can be reflected back to the sky, then UHI can be mitigated. In this study, preliminary results of a project aimed at developing new engobe and glazes on roof and floor tiles are presented. A traditional and commercial floor tile body is chosen to act as the substrate on which the glaze layer is to be coated. Glazes are made by using commercial frits modified in house by adding various oxides to render the coated tiles more reflective especially in the Near Infrared (NIR) region of the solar radiation spectrum. Different pigments are tested to observe their effects on NIR reflection ability. Preliminary results have shown that at least 60% reduction in NIR reflection has been achieved. That means more than half of the solar energy is reflected which means significant reductions in accumulation of heat on roofs and hence in the local area.

Keywords: Cool roof; Urban heat island; Reflective surface coating; Roof tile; Ceramic

1. Introduction

The Urban Heat Island (UHI) is defined as an urban area with higher temperatures than rural areas due to human activities (IEA, 2023; Turhan et al., 2023). Climate change significantly contributes to the intensification of the UHI effect in cities. This leads to increased heat waves and energy consumption in cities during summer, and adverse impacts on public health. As global temperatures rise and extreme weather events become more frequent, climate change further exacerbates the UHI effect (Zhao et al., 2021).

Considering that cities are responsible for approximately 66% of total global energy consumption (Batista et al., 2023), it is important to mitigate the impact of UHI on energy consumption to achieve sustainability goals. Similarly, buildings account for 35% of global energy consumption. Therefore, the impact of UHI on the energy performance of buildings needs to be investigated in detail (Romano, 2021). The literature suggests strategies to reduce the UHI effect to achieve energy savings in buildings. Examples of these strategies include the use of high-reflectivity materials on building surfaces and pavements (Jige et al., 2021; Sedaghat, 2022; Batista et al., 2023), increasing green spaces (Aleksandrowicz et al., 2017), and green roof/green wall applications. Among these strategies, reflective surfaces benefit from industrial processes already used to produce traditional building materials. The manufacturing of reflective ceramic roof tiles is an excellent example of this approach since 25-35% of heat gain in buildings occurs through roof surfaces (Fig. 1) (Hydrosol, 2023).

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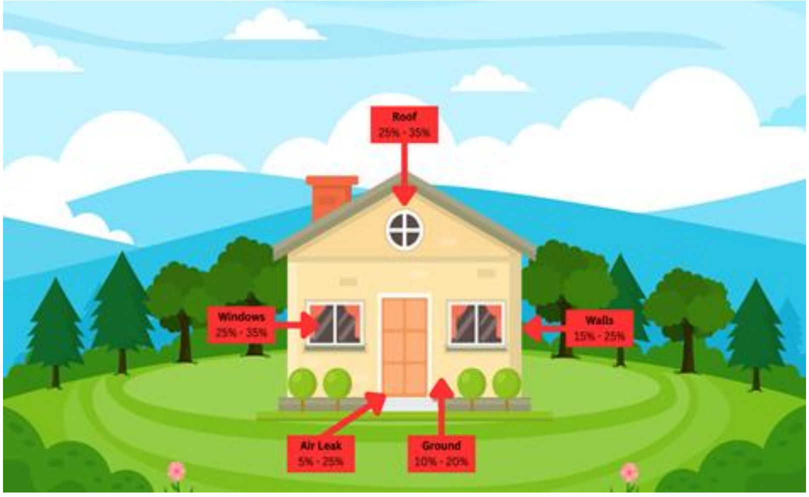


Fig. 1. Distribution of heat gain in buildings (Hydrosol, 2023).

Solar radiation is composed of rays of different wavelengths like gamma rays, x-rays, UV, visible, infrared, etc. As far as the cool roof concept is concerned, the purpose is to reflect as much as possible any part of this radiation from the roofs. Visible light (400 to 700 nm of wavelength) contains 43% of the power in the air-mass, 52% in Near Infrared (NIR) range (700-2500 nm) and 5% ultraviolet (UV) radiation according to ASTM G173-03 (ASTM, 2003). When the surface of the roof tile is completely white, solar-opaque and smooth, NIR reflectance is about 85% (Levinson et.al., 2007). This is the ideal roofing surface but is not desirable for obvious reasons that during sunny days the glare from roofs gives discomfort to people in the cities. Hence, there is an effort in the literature to produce NIR-reflective surfaces that are non-white (Brady et.al., 1992). This can be achieved by forming a coating with high NIR reflectance.

This study focuses on the production of ceramic roof tiles using two distinct approaches: (i) surface modification through the application of reflective coatings (Castellani et al., 2017; Morini et al., 2018) or (ii) modification of the components forming the ceramic tile to give them reflective properties (Ferrari et al., 2013; Ferrari et al., 2014; Governatori et al., 2021). For example, Castellani et al. (2017) developed retro-reflective (RR) coloured ceramic tiles by applying a UV-resistant, transparent paint containing clear solid barium titanate glass microspheres, which increased the reflection of grey (2.6%) and brown (5.1%) tiles. Similarly, Morini et al. (2018) increased the global reflection of a light brown ceramic tile from 30% to 39% by coating it with the same UV-resistant, transparent paint containing RR clear solid titanate microspheres. On the other hand, Governatori et al. (2021) base the development of reflective building surfaces on the modification of the frits and glazes used in ceramic tile products (Ferrari et al., 2013; Ferrari et al., 2014). Revel at al. (2014) developed cool coloured ceramic tiles, acrylic paints and bituminous membranes and tested on the facades of test buildings in Madrid-Spain.

This study proposes the development of novel reflective-glazed tiles to be used on roofs specifically targeting UHI issues in urban areas. Conventional red roof tiles are traditionally made from impure earthenware terracotta compositions which are mostly produced with little control of chemical composition in moderate technology kilns at around 980°C. In addition, the experimental reproducibility in this study would have been poor if terracotta bodies were used. Therefore, in this study, modern floor tiles are chosen as the substrate or the base layer on which to coat the glaze layer a few hundred μm thick. The choice of floor tiles as the substrate is based on the fact that such materials are produced on a mass scale in large quantities, their chemical compositions, physical properties like particle size, surface area before sintering are all well controlled on an industrial scale. So, selection of floor tiles helped eliminate unnecessary loss of resources during the experimental part of the study. Once the proper glaze formulation with maximum reflectivity is developed it is easy to transfer the glaze to a lower melting conventional terracotta roof tile. A local industrial floor tile manufacturer (Seramiksan A.Ş., Turgutlu, Manisa) provided the floor tile body powder in granule form with about 250 μm average diameter. Engobe and frit were also provided by the same company as well as other producers.

2. Materials and Methods

The experimental work followed two main routes: (a) glaze coating composition optimization and (b) scale up of tiles to be used in an experimental roof set-up (1 m^2 area) for thermal performance analysis. In this study, the results of the first part are presented. The work is on-going, and further progress will be reported elsewhere. The flow chart followed in the study is given in Fig. 2. As can be seen in Fig. 2, floor tile granules are compressed in a uniaxial hydraulic press at about 100 MPa to obtain cylindrical pellets of 20 mm diameter and 2 mm height.

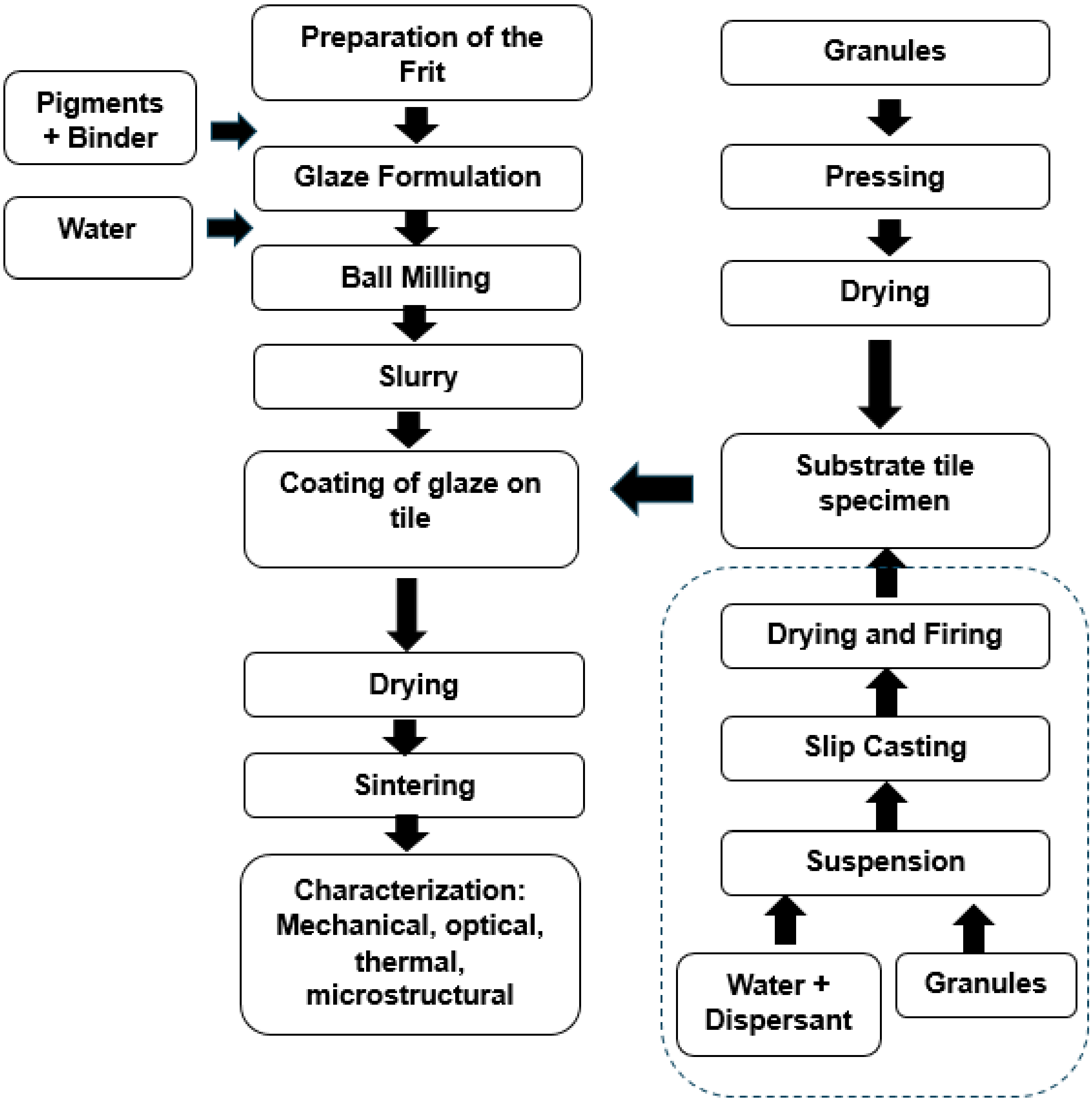


Fig. 2. Flow chart followed during the study.

As these pellets contained about 5% moisture they could be coated with the engobe and glaze layers and sintered safely without worrying about the possibility of drying cracks much. But without a low temperature sintering (bisque-firing) they would not be able to stay in one piece during handling for coating. Consequently, they were all bisque-fired at 800°C for 10 min to impart sufficient strength for handling in the following stages of processing.

Separately, suspensions were prepared for both the glaze (frit + pigment) and the engobe. The glaze suspension was made using 97% frit and 3% pigment oxide mixture. The frit was an industrially used composition provided in pre-melted glass form which was ground to pass completely through a 150 µm (less than 150 µm) particle size. Bisque-fired pellets were dipped by hand in engobe, frit or pigment suspensions sequentially based on the order listed in Table 1. Some samples were coated by frit without an engobe layer. The latter is designed to act as an intermediate layer to hide the darker color of the body and to balance differences in thermal expansion coefficients of the frit and the body.

After coating the bisque-fired body specimens with different layers of different materials (engobe and/or frit), drying was done in an oven at 110°C overnight before sintering at 1200°C for 30 min in line with the industrial practice. All samples showed a good level of attachment to the base layer with pore-free glassy surface. A glaze needs to be protective and water-tight, so maturation of glaze is important and is achieved in this study for all samples. The reflectivity measurements were conducted using a Perkin Elmer Lambda 950 Spectrophotometer. In these measurements, the reflectance in the Near Infrared (NIR) range (i.e. between 700 and 2100 nm) is important and needs to be maximized to obtain sufficient solar reflectance by the glazed surface to be developed in this study (Ferrari et al., 2016). Any radiation outside this range was considered outside the scope of this study as it would be economically/practically prohibitive to try to reflect UV/Visible radiation. Usually, a porcelain floor tile with a white surface offers about 60% reflectivity in this NIR range but cannot be used on roofs or terraces as the white colors gives discomfort for people in the sunny urban areas.

Table 1. Experimental test conditions.

Sample code	Body	Engobe	Frit Code	Pigment	Average NIR Reflectivity (%)
FT*	FT	-	-	-	15
EP*	FT	EP	-	-	36
29	FT	EP	TRS-13	G3*	65
30	FT	EP	TRS-14	G3	58
33	FT	-	5061	G3	54
37	FT	EP	5061	G3	60
40	FT	-	TRS-13	G3	41
42	FT	EP	TRS-13	G1*	58
49	FT	EP	TRS-13	R3*	32
50	FT	EP	TRS-13	Y3*	42

*FT: Floor tile layer; EP: Engobed pellet; G3: Third green pigment; G1: First green pigment; R3: Third red pigment; Y3: Third yellow pigment

3. Results and Discussion

Samples obtained from experiments are shown in Fig.s 3-6. Adhesion of the glaze and engobe to the body was successful in all samples (Fig. 3). All three layers were pore-free and dense. There were no cracks between the different layers. Engobe layer was lighter colored and glassy while the body was less vitrified (glassy). Glaze and engobe layer thicknesses were each about 400 µm.

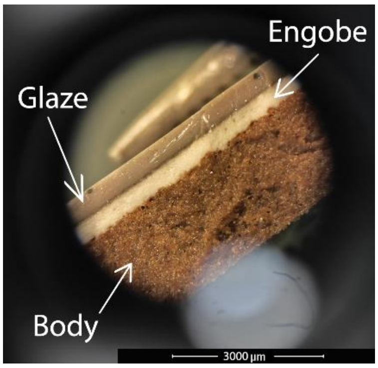
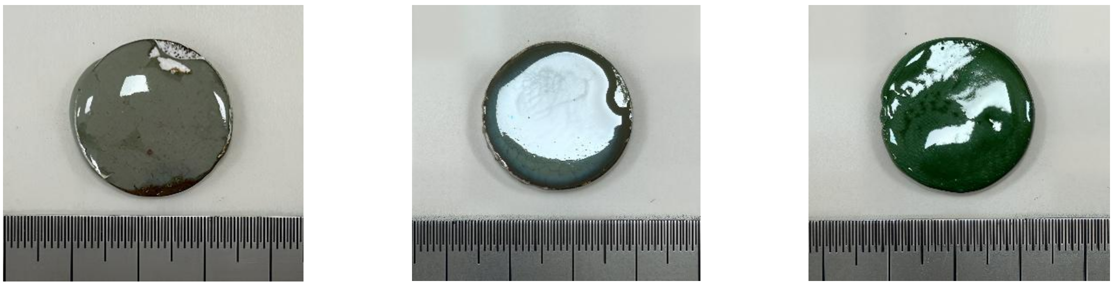


Fig. 3. Cross sectional image of sample 29 in optical microscope. G: Glaze, E: Engobe, B: Body.



Sample: 29 Sample: 30 Sample: 33

Fig. 4. Samples 29, 30 and 33.

Sample: 37 Sample: 42 Sample: 49

Fig. 5. Samples 37, 42 and 49.

Sample: FT Sample: EP Sample: 50

Fig. 6. Samples FT, EP and 50.

Reflectivity measurements of the samples are shown in Fig.s 7 to 11. In Fig. 7, the reflectivities of the base body layer (FT), the engobe (EP) and glaze (frit + pigment) layers are shown. Considering that the base layer had about 15% reflectivity, the effect of the engobe layer can be clearly seen to make a remarkable effect on reflectivity (36%). When the glaze layer is applied on the engobed layer further significant improvements could be achieved. Sample 29 with only a small amount of chromium as pigment showed significant increases in reflectivity well in excess of 65%. This sample provided the authors with a high amount of confidence in achieving high reflectivity without going ”white” which is undesirable due to sun-glare effects. Therefore, the key in achieving high reflectivity was to avoid using white color Ferrari et al., (2016). Sample 29 had a green color which should be acceptable as a roof cover material. This is up to the final users's decisions.

The effect of the presence of an engobe layer was investigated in samples 29-40 and 33-37. Samples 33 and 40 had no engobe layer but they were coated by a glaze layer. Samples 29 and 37, however, had all the layers coated sequentially. The purpose was to test whether the presence of the engobe layer would make much difference. It was found that the engobe layer was quite effective in providing higher reflectance as shown in Fig.s 8 and 9.
The effect of the type of frit was investigated in samples 29, 30 and 37 which contained different industrial frits. The results are shown in Fig. 10 where sample 29 was found to be most effective in providing the highest reflectivity. This sample contained the frit coded “TRS-13” which is selected as the frit to be used in the rest of the experimental program.

Once it was decided that the engobe layer was useful and the best frit was TRS-13, the study was directed toward studying different pigment types. As there are several different pigments available in the market, the selection of pigment was restricted to only four colors: green, red, yellow and black. The measurements for the samples with black pigment was not ready to report here so these results will be reported elsewhere. Fig. 11 shows the results from samples 29, 42, 49 and 50 which contained green, another green, red and yellow pigments. As can be seen in Fig. 11, the green pigment was found to be most effective in providing the highest reflectance values (around 65%). The study is ongoing, and other pigments are investigated to further maximize reflectivities.

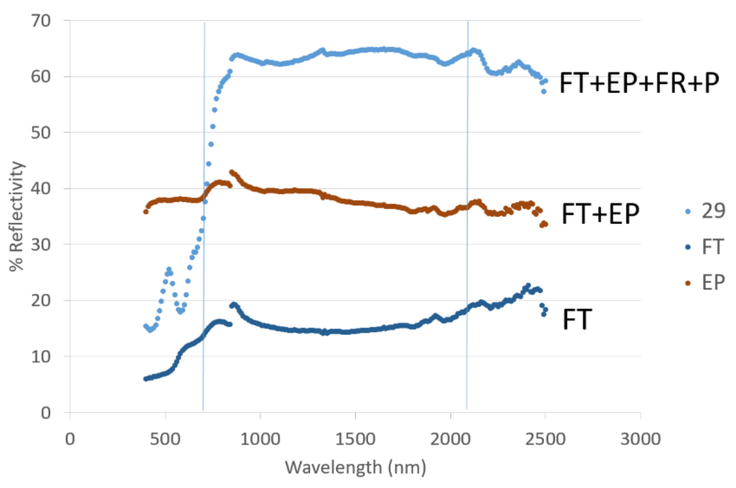


Fig. 7. The results of reflectivity measurements of samples FT, EP and 29.

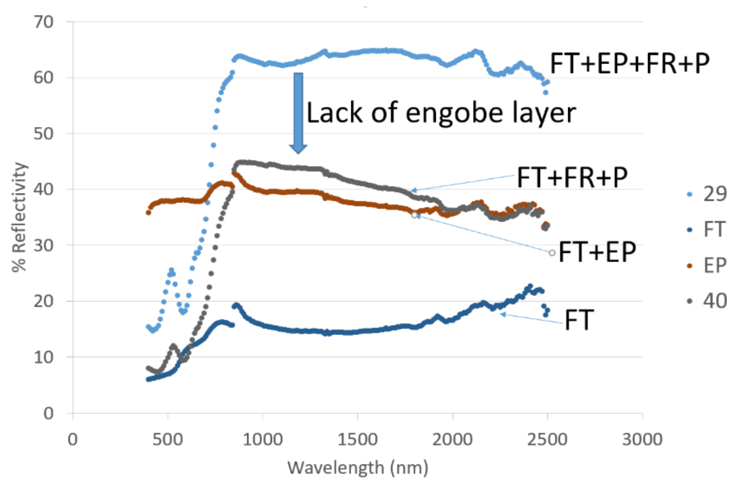


Fig. 8. The results of reflectivity measurements of samples FT, EP, 29 and 40.

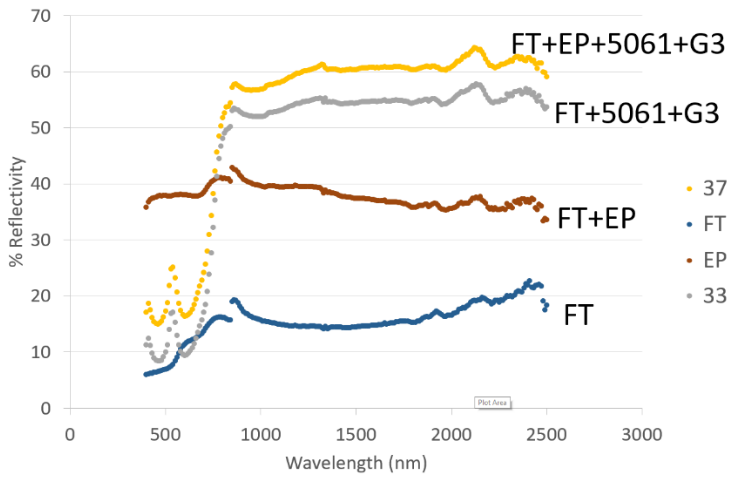


Fig. 9. The results of reflectivity measurements of samples FT, EP, 33 and 37.

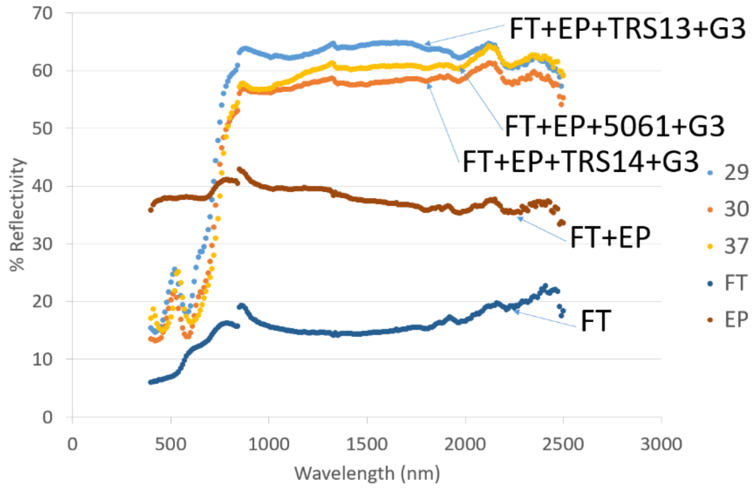


Fig. 10. The results of reflectivity measurements of samples FT, EP, 29, 30 and 37. Three different frits are compared. The best one was the frit TRS-13 that was used in sample 29.

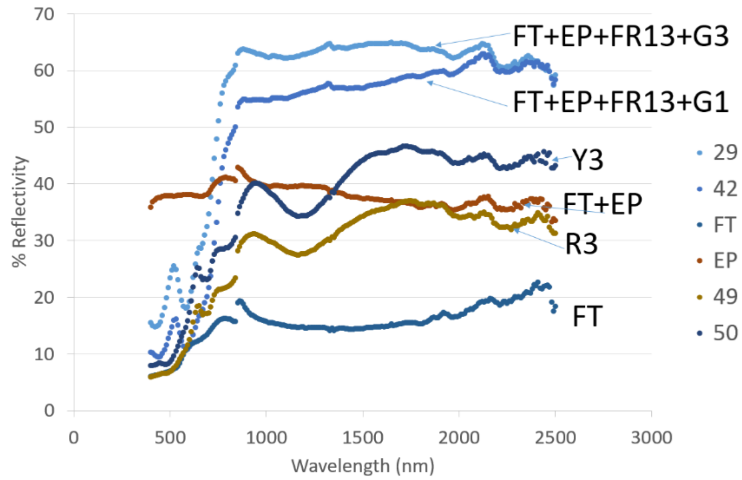


Fig. 11. The results of reflectivity measurements of samples FT, EP, 29, 42, 49 and 37. Different pigments are compared. The most effective pigment was chromium containing G3.

4. Conclusions

Laboratory work involving floor tile pellets coated with engobe and glaze layers proved to be successful in obtaining glaze coatings that provided high reflectivity in the NIR spectrum of solar radiation. Tile samples produced in this study were free from pores, cracks, air bubbles and were composed of different body, engobe and glaze layer combinations that were well-bonded to each other. Solar reflectivity measurement results were promising in that the continuation of the work will involve scale up which means to produce larger tiles to cover experimental roofs. The research effort is already ongoing to analyze thermal effects of the new tiles which eventually are planned to lead to minimization of UHI effects.

- Tile samples were successfully coated with engobe and glaze layers using different pigments.
- Engobe layer proved to be effective in increasing reflectivity in the NIR range which is beneficial in mitigating UHI effects.
- Among the different frits, TRS-13 was found to be most effective in providing the highest reflectivity.
- Chromium containing pigment was the most effective in providing high reflectivity while red and yellow pigments were poor in that regard.

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Evaluating risks in the 3D concrete printing process: 5x5 matrix approach

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Abstract. Three-dimensional printing technology offers important advantages such as increasing production speed, reducing material waste, and design flexibility in the construction industry. However, due to its developing structure, this innovative method's applicability brings various risk factors. This study used the 5x5 risk assessment matrix method to identify and evaluate potential risks that may arise in the 3d concrete printing process. Based on the data obtained from the literature, 17 basic risk factors were analysed according to likelihood (L) and severity (S) levels and risk scores were determined. According to the findings, 1 of the 17 risk factors (nozzle characteristics) was 'unacceptable', 11 (motion control, open exposure duration, cybersecurity risks, wall joint detail and design, lack of knowledge and experience, inadequate safety measures, lack of skilled labor, inadequate setting time, insufficient extrudability, Inadequate infill density) were 'high risk', 1 (complex working environment) was 'medium risk' and the remaining 4 (wind, temperature, relative humidity, radiation and chemical material) are classified in the 'low risk' category. In this context, it is pointed out that risk assessment is necessary in multifaceted and interdisciplinary issues such as printing material properties, environmental status, construction site, design decisions, safety and printer property parameters. For this reason, it is thought that the development of integrated risk assessment models covering many different areas, such as not only occupational health and safety, but also structural integrity, production efficiency, cyber security and environmental impacts, will increase the applicability and efficiency of the technology. In this direction, studies based on comparative analysis of applications carried out under different conditions can contribute to developing academic literature in the field by increasing the knowledge of additive manufacturing technology.

Keywords: 3D concrete printing; Risk analysis; Additive manufacturing technology; 5x5 Matrix method; Risk assessment

1. Introduction

Three-dimensional printing (3DP) technology stands out as a revolutionary innovation in the construction industry and enables the construction of structures and elements based on the principle of additive manufacturing. This technology enables the integration of computer-aided design (CAD) and robotic systems to create structures by extruding materials such as concrete layer by layer using specially designed large-scale three-dimensional printers. Unlike traditional moulded concrete pouring methods, this process, which is based on the principle of moldless production, offers many important advantages such as less human intervention, minimum material waste and shortening of construction time. In addition, it increases design flexibility by allowing the production of customised architectural forms with structures with complex geometry. Due to its important advantages, it is also applied in many industrial areas today (Tay et al., 2016; Wu et al., 2016).

Despite the significant advantages and promising potential of 3D printing in the construction industry, several uncertainties and risks regarding the viability of this technology still remain. 3D printers are automated and mechanical systems with inherent risks; therefore, various factors such as downtime and maintenance costs should be carefully analyzed for their impact on the overall risk level of the 3D printing process (Ahmed et al., 2025). Although many studies to date have addressed the risks in construction projects, there is limited research in the literature to comprehensively examine the risks that 3D concrete printing technology may pose in construction projects. The application of new technologies brings with it additional risks that are unique compared to traditional methods. The main objective of this study is to identify and systematically evaluate the new risks that this technology may cause in 3D concrete printing projects in the construction industry using the 5x5 Matrix method.

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In this study, the applicability of 3d concrete printing technology, which is becoming increasingly widespread in the construction industry, is addressed from a risk management perspective. The objective is to identify, analyse, and evaluate process-specific potential hazards in a systematic manner.

In this context, various risk dimensions, including worker safety, structural performance, and production efficiency, were assessed using a 5x5 risk matrix approach. This assessment proposes preventive strategies to support integrating safe and sustainable technology into construction practices. The study identifies 17 key risk factors associated with 3d printing in construction and comprehensively evaluates the applied methodology and its outcomes.

2. Methodology

Risk assessment results play a critical role in minimising the risks of accidents and deaths by prioritising the work and maintaining the operational flow. The 5x5 Matrix method offers a more reliable and objective evaluation process by minimising the margin of error in risk rankings thanks to its complete numerical data. Unlike traditional construction methods, the increasing prevalence of three-dimensional concrete printing technology, especially in the construction sector, brings new and hard-to-predict risks. In this context, the method determined within the scope of the study stands out as an effective assessment tool in terms of identifying, sequencing and controlling the risks related to issues such as operational, technical and occupational health that may arise in three-dimensional concrete printing processes. It is thought that it is a suitable method for the scope of this study in terms of allowing the evaluation of new and uncertain risks that three-dimensional printing technology may pose in construction projects with a quantitative, systematic and prioritisation-based approach.

Within the scope of this study, the definitions and steps for the 5x5 Matrix risk assessment method will be detailed, and then calculations will be made with the risk factors determined by the data obtained from the literature within the scope of the subject. Fig. 1 shows the flowchart of the research.

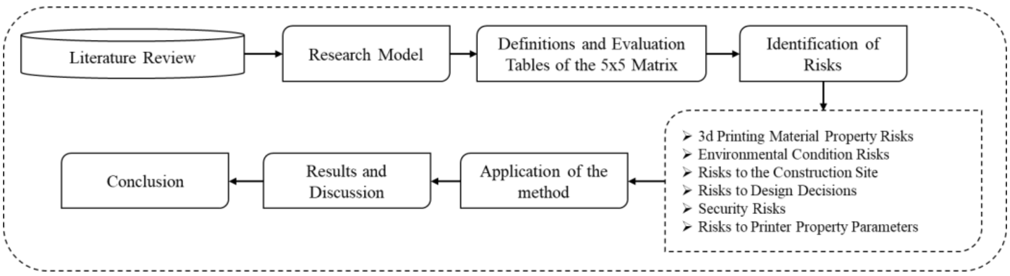

Fig. 1. Flowchart of the study

2.1. 5x5 Matrix risk assessment method

The construction industry is an area where risk management is vital due to its high potential for hazards. Especially in terms of occupational health and safety, it is necessary to identify, analyse and control possible risks in advance. The 5x5 risk assessment matrix, one of the methods used in this framework, enables the hazards encountered in the sector to be examined with a systematic and holistic approach.

The 5x5 Matrix is a practical risk assessment method used especially in analysing cause-effect relationships. With this method, first of all, it is ensured that the probability of occurrence of an event and the effect it will have if it occurs are graded and quantitatively measured (Özkılıç, 2005). The risk score is obtained from the product of likelihood and severity (degree of harm) and is written in its place in the table (Equation 1). Reviewing the literature shows that the definitions of risk, severity, and likelihood are largely framed in the context of occupational health and safety (Aker, 2020; Gur et al., 2021; Öztürk & Şimşek, 2020). This limited approach to various risk assessments prevents accurate and clear assessments. The relevant tables are given in Tables 1 and 2.

$$\text{Risk Score (RS)} = \text{Likelihood (L)} \times \text{Severity (S)} \tag{1}$$

Table 1. Severity values in the event of an incident (Özkılıç, 2005)

Event	Violence	Severity Value
In the event of multiple deaths or permanent incapacity for work	5	Very serious
In case of major injury or occupational disease	4	Serious
In case of injuries requiring rest	3	Middle
In case of minor injuries requiring first aid (no loss of work)	2	Light
In case of accidents that require only simple first aid without loss of work	1	Very Light

Table 2. 5x5 Matrix Probability Value (Bekdemir, 2019)

Frequency	Likelihood	Likelihood value
Once a year	Too small	1
Quarterly	Small	2
Once a month	Middle	3
Weekly	High	4
Everyday	Very high	5

Table 1 refers to the severity values in case of an event, Table 2 refers to the 5x5 Matrix likelihood value, and Table 4 refers to the risk score matrix. According to this table, risk is grouped into four groups: 'low, medium, high and unacceptable' risk. The data obtained from Tables 1 and 2 are recorded in the analysis table in line with the matrix-based risk assessment approach (Table 4), and the necessary improvement measures are applied according to the action steps specified in Table 5, starting with the one with the highest risk score. After the relevant measures are implemented, each risk factor should be re-evaluated, the current risk score should be determined, and the evaluation form should be prepared accordingly. It should be restructured.

Due to the unique nature of these applications, the literature has shown that definitions and evaluation parameters (Ball & Watt, 2013; Duijm, 2015; IEC/ISO, 2009; Jensen et al., 2022) state that it needs to be restructured to align with the objectives of the study. In this regard, the evaluation team, experienced in the 3d concrete printing process, developed the scale presented in Table 3 to fit the content of the study. Calculations were made accordingly.

Table 3. Severity values in the case of events that can occur in the 3d concrete printing process

Event	Severity	Severity Value
There is complete failure in the 3d concrete printing process. The system stops due to the failure of critical components. The manufactured elements are completely dysfunctional. There are serious delays in project delivery. It is necessary to redo the production.	5	Very serious
The elements produced are technically unacceptable. Requires reproduction. Loss of material and time occurs. Delays occur in delivery dates. The efficiency of the production process is significantly reduced.	4	Serious
There are quality problems in the printed elements, but they are not out of use. Partial rework or correction may be required. There is a limited impact in terms of cost and time. There may be short-term disruptions in operational flow.	3	Middle
There is a small level of aesthetic or functional deterioration in the product. The part is available. The process continues, but there may be minimal loss of productivity. Additional costs are non-existent or negligible.	2	Light
The process was completed without any problems. The final product is technically and aesthetically acceptable. There is no negativity in time, cost and quality parameters.	1	Very Light

Table 4. Risk Score (Rating) Matrix (Özkılıç, 2005)

OxS	Violence				
Probability	1	2	3	4	5
1	Low (1)	Low (2)	Low (3)	Low (4)	Low (5)
2	Low (2)	Low (4)	Low (6)	Medium (8)	Medium (10)
3	Low (3)	Low (6)	Medium (9)	Medium (12)	High (15)
4	Low (4)	Medium (8)	Medium (12)	High (16)	High (20)
5	Low (5)	Medium (10)	High (15)	High (20)	Unacceptable (25)

Table 5. Admissibility Values of the 5x5 Method Risk Result

Risk Value	Assessment	Risk Assessment Result (Action)
Unacceptable Risk	(25)	Work should not be started until the identified risk is reduced to an acceptable level; if there is an ongoing activity, it should be stopped immediately. The activity must be prevented if it is impossible to reduce the risk despite the measures taken.

Tablo 5 continued.

High	(15,16,20)	Work should not be started until the identified risk is reduced, and if there is an ongoing activity, it should be stopped immediately. If the risk is related to the continuation of the business, urgent measures should be taken, and as a result of these measures, the continuation of the activity should be decided.
Medium	(8,9,10,12)	Activities should be initiated to reduce the identified risks. Risk mitigation measures may take time.
Low	(2,3,4,5,6)	Additional control processes may not be needed to eliminate the identified risks. However, existing controls should be maintained, and it should be ensured that these controls are maintained
Negligible risk	Negligible	In order to eliminate the identified risks, it may not be necessary to plan control processes and keep records of the activities to be performed.

3. Risk identification

Construction risk management is a structured management process that includes the systematic identification and analysis of uncertainties that may be encountered throughout the life cycle of a construction project and the development of appropriate response strategies to these risks; It is a structured management process whose purpose is to eliminate, reduce or control risks and to achieve project goals safely and effectively (Wang et al., 2004; Ahmed et al., 2025). Risk analyses predict the consequences that may arise if the project does not progress according to plan. No matter how advanced analytical techniques are, the correct interpretation of data depends on expertise. Evaluations with systematic analyses instead of heuristic approaches offer a clearer, more reliable view of risks (Uğur, 2006).

Risk management in construction projects is a systematic and structured approach that aims not to eliminate all risks, but to prioritize and manage the most important and effective ones. There is a certain level of risk inherent in every project; Some of these risks are acceptable as they are associated with the potential returns of the project. However, at an early stage, identifying and effectively controlling the risks that pose a direct threat, such as the project's duration, cost and quality, is critical. In this context, a successful risk management process depends on technical analysis and the organisation's continuous and proactive approach to risks. Such a risk management approach is important in applying technology safely, efficiently, and sustainably, especially in areas such as 3d concrete printing technology, where rapidly developing and innovative applications occur.

Geometric decisions made during the design phase in 3d printing technologies directly shape the success and risk level of the production process (Takva et al., 2024; Gebel et al., 2024). For this reason, it is important to integrate architectural design parameters into risk assessment processes to implement the technology in a safer and more efficient way. This section explains the multifaceted risks of 3d printing by grouping them into 6 main categories. Table 6 provides detailed information on the definitions and references of these risks encountered in construction projects. A total of 17 risk factors were identified within the scope of this study.

- 3d Printing Material Property Risks: These are the material properties related to the physical and mechanical properties of the material used in the 3d printing process. Using different materials or mixing ratios of the components in the studied material properties specific to the concrete material is effective in the final 3d printed product.
- Environmental Condition Risks: These include various external factors that affect the 3d printing process, such as temperature, humidity, wind, etc., so that other parameters work effectively. The print environment directly or indirectly affects the final product.
- Risks to the Construction Site: It refers to potential hazards that may threaten safety, accessibility and operational integrity in relation to the physical environment, equipment, workforce and processes in the area where 3d concrete printing technology is used.
- Risks to Design Decisions: It covers the characteristics of the final product produced with a 3d printer. In the final product, static factors are important, including the structure's geometry, size, and complexity.
- Security Risks: Cybersecurity risks in 3d printing refer to situations where digital design data and production processes are compromised by unauthorised access, data integrity is compromised, or interference with the system's operation.
- Risks to Printer Property Parameters: These are the printer features that depend on the structural features of the 3d printer. The change in printer types changes the efficiency of the printing process, its cost, and the production process. At this point, the printer's features are very important in the 3dp process.

The concepts of risk and danger are explained in the literature. Risk is the possibility of loss, injury, or other harmful consequences resulting from the hazard. On the other hand, danger is the potential for harm or damage in the workplace or may come from outside, affecting the employee or the workplace (Aker, 2020). The definitions in Table 7 are discussed within this framework.

Table 6. Risks of 3D printing in construction projects

Main title	N	Risk	Definition	Reference
3D Printing Material Property Risks	1	Inadequate infill density	In 3D printing, fill density refers to the amount of material used to fill the internal structure of the printed product. The high fill density means that there will be fewer gaps within the structural elements. This can make the structure more robust and resistant to impacts. Depending on the application and the desired properties of the structure, the most common fill densities range from 10% to 50%.	Lyu et al, 2021 Qaidi et al, 2022 Ćwikła et al, 2017 Gosselin et al, 2016 Karalia et al, 2021
	2	Insufficient extrudability	It is the ability to continuously squeeze concrete out of the nozzle, and this property depends on the fluidity. If concrete is not fluid, it cannot be extruded; if it cannot be extruded, it cannot be printed.	Malaeb et al, 2019
	3	Inadequate Setting Time	It is the time until the concrete is completely solidified.	Günzel, 2021 Lyu et al, 2021 Özalp and Yılmaz, 2020
Environmental Status Risks	4	Relative Humidity	In outdoor printing processes, adjustments to the mixing ratios of concrete materials are required according to current temperature and humidity levels to optimise printability and extrudability parameters.	Diggs-McGee et al, 2019 Ma et al.,2022 Moelich et al, 2022
	5	Temperature	Evaporation of moisture from pressurised concrete can inhibit the hydration of cement and affect the development of mechanical properties; temperature and wind, on the other hand, affect the behaviour of concrete printing materials.	Diggs-McGee et al, 2019 Ma et al.,2022
	6	Wind	Low humidity and high wind speeds can exacerbate surface moisture evaporation in concrete printing, potentially leading to filament cracking.	Ma et al.,2022 Moelich et al, 2022
	7	Radiation & Chemical Material	Exposure to ultraviolet radiation and chemicals can compromise the structural integrity of concrete products, highlighting the need for regulations tailored to environmental factors to ensure the product's durability.	Pacewicz et al, 2018 Siddika et al, 2020
Risks to the Construction Site	8	Lack of skilled labour	New technologies used in the construction industry pose a significant challenge due to limited access to a qualified and experienced workforce, especially in countries where these methods have not yet become widespread.	(Hwang et al., 2017)
	9	Complex working environment	The overall complexity of the workspace and the different levels of access can create a challenging working environment for robots.	(Ahmed et al., 2025)
	10	Inadequate safety measures	Operational hazards caused by electrical and mechanical causes can lead to injuries, considered the most serious industrial accidents.	(Ahmed et al., 2025)
Risks to Design Decisions	11	Wall Design	Wall design consists of fill density and wall combination. In construction projects where 3D concrete printers are used, the design of the wall to be printed plays an important role in the printing process. In this process, the material properties, geometry and design of the wall type to be printed affect the print quality, durability and cost of the final product.	Gosselin et al., 2016 Khan et al, 2021 Martínez-Rocamora et al, 2020 Žujović et al, 2022 Lim, 2023
	12	Wall joint detail	The wall connection affects the strength, durability, and overall performance of the structure. Form corner joints can be created at different angles for aesthetic concerns, costs, durability performance and functional features. Angled corner joints are generally simpler and less costly, increasing the rigidity of the structure.	Lim, 2023 Marais et al, 2021 Suntharalingam et al, 2021 Wang et al, 2020

Table 6 continued.

Main title	N	Risk	Definition	Reference
Risks to Design Decisions	13	Lack of knowledge and experience	Lack of knowledge and experience on the subject can cause structural errors and serious risks in occupational health and safety. For example, due to the inability to determine the optimum distance between the nozzle tip and the base level, unsuccessful/defective products may occur in varying geometries.	Jo et al., (2020)
Security Risks	14	Cyber Security Risks	The fact that 3d printers work with CAD files increases cybersecurity risks, such as unauthorised access to the system and unauthorised modification of the parameters of the printing process.	(Ahmed et al., 2025), (Zeltmann et al., 2016)
Risks to Printer Property Parameters	15	Open exposure duration	Open exposure duration refers to when cement or similar materials can flow through the printer nozzle without clogging. Continuous operation of the printer causes its hardware to heat up due to heat dissipation and friction, which affects the uptime.	Jo et al., 2020 Mueller et al., 2015
	16	Nozzle Features	It includes parameters such as the speed of movement of the nozzle, the size of the nozzle's tip and the nozzle's height. Nozzle characteristics are important in optimising print quality and making printing more efficient.	Blank et al, 2016 Jo et al, 2020 Lyu et al, 2021 Tay et al., 2016
	17	Motion control	It determines the movement of the nozzle and how the material is layered to create the object to be 3d printed. Motion control ensures that printers operate correctly and, as a result, improves production quality. It also improves energy efficiency by helping to manage printer movement more efficiently.	Blank et al, 2016 Lyu et al, 2021 Zhao et al, 2019

4. Results and Discussion

In this study, 17 different risk factors that may be encountered during the application process of 3d concrete printing technology in the construction sector were defined, and the risk score (RS= LxS) was calculated for each of them based on the likelihood (L) and severity (S) values. The scores obtained are given in Table 7. Fig. 2 provides a visualisation of these risk scores. Accordingly, the risks were evaluated in four categories: unacceptable, high, medium and low. Risk scores were analysed according to a scale ranging from 1 to 25 within the framework of this method. According to the findings, 1 of the 17 risk factors was classified as 'unacceptable', 11 as 'high risk', 1 as 'medium risk' and 4 as 'low risk'.

The only parameter with an unacceptable level of risk is 'nozzle characteristics'. This situation shows that the elements that directly affect the printability and structural integrity of the product can pose a threat that can lead to serious consequences. In particular, the fact that nozzle properties can directly cause production defects can create serious operational risks that may result in material deformation, loss of time and material damage.

It is seen that the risks that may occur in the high-risk group for 'motion control, open exposure duration, cybersecurity risks, wall connection and design' are of critical importance. Inadequacies in the motion control system affect production precision, causing structural imbalances, which in turn affect the mass manufacturability process. The risks to wall design and connection reveal the sensitivity of the relationship between digital modelling and material behaviour in the 3d printing process, and reveal the necessity of considering design processes, engineering controls and connection details with a holistic approach. Although cybersecurity risks are often overlooked in digital manufacturing processes, they are critical, especially in CAD-based automation systems such as 3d concrete printing. Unauthorized modification of system data or vulnerability to external interference of print parameters can lead to serious manufacturing defects and structural security vulnerabilities. This situation shows that cybersecurity has become an important component of the IT and construction industries. These risks are followed by 'lack of knowledge and experience, inadequate safety measures, lack of skilled workforce, inadequate setting time, insufficient extrudability and inadequate infill density'. Risks related to a lack of knowledge and experience increase the potential for wrong decision-making in the process, which can threaten both production efficiency and occupational health and safety.

The 'complex working environment', which is evaluated in the medium risk group, and the physical complexity in the environments/sites where 3d concrete printing is applied, make the effectiveness of robotic systems difficult.

Although environmental factors such as 'wind, temperature, relative humidity', which are classified as low risk, do not directly affect the success of the printing process, there is the potential for the risk level to increase over time if neglected. Therefore, these risks need to be managed through periodic monitoring and control mechanisms.

As a result, the analysis revealed that although 3d concrete printing has important opportunities for the construction industry, it contains multidimensional and technology-specific risks. Unlike traditional construction risks, the risks in this technology can be various sources, such as a lack of knowledge and experience about technology, software, and environmental ffactors. For this reason, in the risk management process, occupational health and safety and interdisciplinary elements such as cyber security, structural design, production continuity and efficiency should be evaluated holistically.

Table 7. 3D concrete printing process risk assessment results

No	Main Topics	Danger	Risk	L	S	Risk Score
1	3d Printing Material Property Risks	Inadequate infill density	Mechanical weakness, mass manufacturability problem, loss of time and money	4	4	16
2	3d Printing Material Property Risks	Insufficient extrudability	Printing failure, loss of time and money	4	4	16
3	3d Printing Material Property Risks	Inadequate setting time	Mass manufacturability problem, printing failure, loss of time and money	4	4	16
4	Environmental Status Risks	Relative humidity	Material deformation, loss of time and material	2	2	4
5	Environmental Status Risks	Temperature	Thermal expansion/cracking, material deformation, time and material loss	2	2	4
6	Environmental Status Risks	Wind	Material drying instability, material deformation, time and material loss	2	2	4
7	Environmental Status Risks	Radiation and chemical exposure	Health problem, material deformation, time and material loss	1	4	4
8	Risks to the Construction Site	Lack of skilled labour	Incorrect/incomplete operation, operational disruption, time and financial loss	5	3	15
9	Risks to the Construction Site	Complex working environment	Collision, imcorrect/incomplete operation, operational disruption, injury or death, property loss	4	3	12
10	Risks to the Construction Site	Inadequate safety measures	Injury or death, loss of property	4	4	16
11	Risks to Design Decisions	Wall design	Structural imbalance, constructability problem, mass manufacturability problem, time and material loss	5	4	20
12	Risks to Design Decisions	Wall joint detail	Structural imbalance, constructability problem, mass manufacturability problem, time and material loss	5	4	20
13	Risks to Design Decisions	Lack of knowledge and experience	Wrong decision-making, incorrect operation, operational disruption, time and financial loss	4	4	16
14	Security Risks	Cybersecurity risks	Data loss, security vulnerability, incorrect transaction applications, loss of time and money	4	5	20
15	Risks to Printer Property Parameters	Open time (or open exposure duration)	Mass manufacturability problem, mechanical problems, material deformation, time and material loss	5	4	20
16	Risks to Printer Property Parameters	Nozzle characteristics	Clogging, uneven flow, mass manufacturability problem, mechanical problems, material deformation, time and material loss	5	5	25

Table 7 continued.

No	Main Topics	Danger	Risk	L	S	Risk Score
17	Risks to Printer Property Parameters	Motion control	Mass manufacturability problem, mechanical problems, material deformation, time and material loss	5	4	20

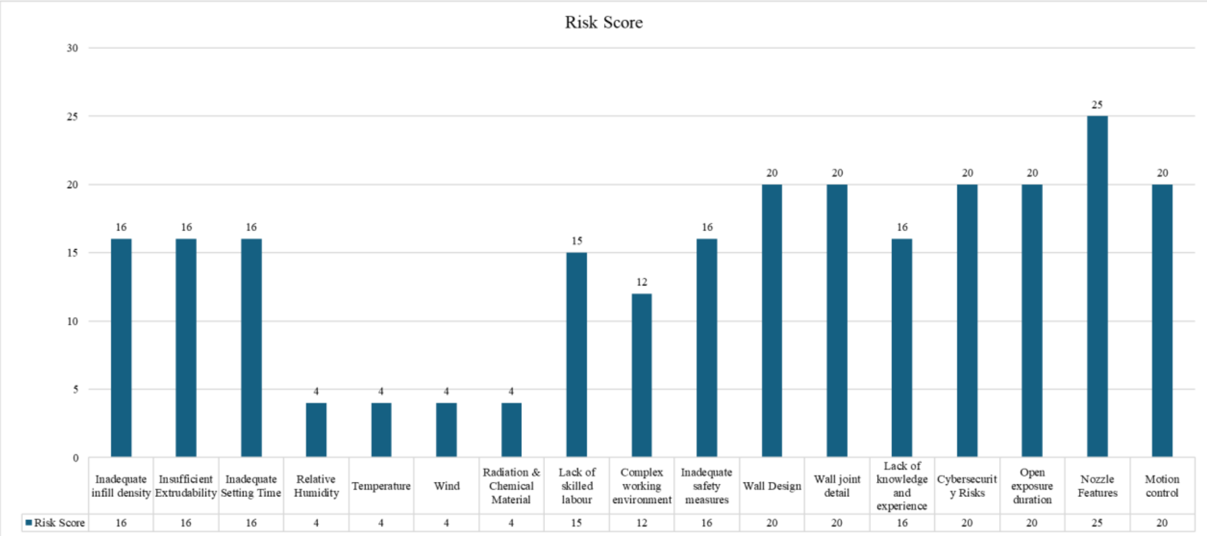

Fig. 2. Risk score table

5. Conclusion

3d printing technology greatly transforms the construction industry with its many advantages, such as cost, speed and design flexibility. Thanks to advances in this technology, producing environmentally sustainable and cost-effective structures with complex geometries that are difficult to construct with traditional methods is becoming possible. It is expected that in the future, this technology will become fully widespread and one of the mainstream construction methods. However, there are issues that need to be addressed in many areas, from materials science to building regulations. In addition to this situation, when we look at the applications of 3d printing technology in the construction sector, it is seen that despite its structural and production advantages, it also has multifaceted risks. Within the scope of this study, the 5x5 risk assessment matrix method, which is used to systematically identify and prioritise risks, allows the objective analysis of 17 basic risk factors specific to this technology. The findings point to the necessity of risk assessment on multifaceted and interdisciplinary issues such as printing material properties, environmental status, construction site, design decisions, safety and printer feature parameters. Therefore, for 3d printing technology to be applied safely and efficiently in the field, it is recommended to go beyond the traditional occupational health and safety framework and adopt an integrated risk management approach.

Developing risk management capacity and raising awareness in this field in construction projects where 3d printing technology is applied is important in preventing possible project failures. On the other hand, it is thought that this situation may also be beneficial in ensuring the sustainability of sectoral transformation. At this point, studies on risk assessment are considered necessary for the efficient, safe and widespread adoption of new technologies.

Future studies should address the potential risks that 3d printing technology may encounter in different construction applications with a more comprehensive and multidisciplinary approach. In this context, it is thought that the development of integrated risk assessment models covering many different areas, such as occupational health and safety, structural integrity, production efficiency, cyber security and environmental impacts, will increase the applicability and efficiency of the technology. In addition, it is thought that it may be possible to increase the accuracy and effectiveness of existing risk analysis methods in decision-making processes through experimental research and risk modelling supported by field data. On the other hand, the development of the subject in the international literature can be supported by increasing the sharing of information on additive manufacturing technology with studies in which the applications carried out under different conditions are discussed comparatively.

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Evaluation of energy-efficient passive design parameters in traditional Ayvalık houses

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Abstract. Since the 1970s, important steps have been taken to prevent climate change and reduce the effects of global warming on a global scale. In this context, the construction sector, which has a large share in energy use and carbon emissions, is also taking precautions and developing strategies. To promote sustainability on a global scale, various initiatives have been introduced to enhance the energy efficiency of both new and existing buildings. Considering that energy-efficient design parameters are also adopted in traditional structures, examining the construction techniques of these structures and applying them to current structures can significantly contribute to reducing energy consumption and carbon emissions.
Within the scope of the study, Traditional Ayvalık houses, which are preserved close to their original state and are still in use in Ayvalık, which is registered as a historical and natural site, were examined. Ayvalık district, located in the west of Turkey, is located in the temperate climate zone according to the TS825 standard. This study aims to examine the energy-efficient passive design parameters adopted in Traditional Ayvalık houses and to reveal the energy efficiency potential of these structures. Energy efficient passive design parameters were evaluated and explained in terms of settlement and orientation, building form, material use and construction techniques. Data collection, archive work, in-situ observation and physical examination methods were used in these evaluations. As a result of the study, passive design parameters adopted in traditional Ayvalık houses were presented. In addition, the advantages of using these parameters for new structures in similar climate zones were explained. Future studies that can be done to develop the study are listed.

Keywords: Sustainability; Energy efficient design; Passive design parameters; Traditional houses; Ayvalık houses.

1. Introduction

Industrialisation and population growth bring about important innovations in the construction sector in areas such as construction systems, material diversity, production, and planning. These innovations provide time, labour, and cost savings while causing an increase in energy consumption and carbon emissions. According to current data, approximately 40% of global energy consumption and one-third of carbon emissions originate from the building sector. To ensure sustainability on a global scale, energy-efficient approaches need to be implemented in new and existing structures. Therefore, considering that energy-efficient design parameters are adopted in traditional structures, examining the construction techniques of these structures and applying them to existing and current structures will contribute to reducing energy consumption and carbon emissions.

Historical buildings were constructed using energy-efficient systems that incorporated locally sourced materials and were specifically designed to respond to prevailing climatic conditions. A systematic analysis of these vernacular design approaches and their integration with contemporary technologies can provide insights for enhancing the energy performance of modern buildings.

This study examines Ayvalık houses, located in a temperate humid climate zone and registered as a historical and natural conservation site. Ayvalık, which began to develop in the mid-18th century, functioned as a port city predominantly inhabited by Greeks until the population exchange in the early 20th century. The density of registered heritage buildings, the use of local materials and the housing texture compatible with the climate make this region a unique case study in terms of energy efficiency.

In the literature review, it was found that studies were conducted in the field of architectural design and restoration regarding Ayvalık houses, examining plan typologies (Hayta, 2011; Tibet, 2013; Özker, 2020), façade features (Akın, 2015; Şaşkın, 2020) and façade elements (Efe, 2020). Additionally, studies have been conducted to document and analyse registered structures in the restoration area (Yıldırım Gönül, 2004; Uztuğ, 2006; Asımgil,

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2013; Çamkaya, 2023). However, it has been determined that there is no comprehensive study focusing on the energy efficiency of traditional Ayvalık houses built in their original texture and harmony with the climate. Although studies have been conducted on energy efficiency in traditional structures located in different climate zones, it is remarkable that no such study has been conducted in Ayvalık houses. In this context, the study aims to analyse the passive design principles adopted in traditional Ayvalık houses, to identify applicable variables for designing climate-responsive buildings, and to reveal the energy efficiency potential of these vernacular structures. In line with this goal, traditional stone houses located in the moderately humid climate region were analysed with data collection, archive work, on site observation and physical examination methods. The buildings were evaluated based on passive design criteria, including site layout and orientation, building form, spatial organisation, building envelope design, and material usage. Based on the findings, the passive energy efficiency strategies observed in traditional Ayvalık houses are presented, and their potential integration into contemporary architectural design processes is discussed.

2. Methodology

In this study, the field research method, a qualitative research approach, was employed. Ayvalık district was selected as the case study area in line with the research objectives. The high density of historical structures in Ayvalık, the fact that the structures are largely registered and preserved in a way close to their original state, were effective in this selection. Traditional Ayvalık houses built at different scales, with similar features and in harmony with the local climate, were examined within the scope of the study.

Data collection was carried out through archival and document analysis, on-site observations, and physical assessments. Historical data, architectural plans, registration documents, and previous restoration records were examined through archival and document review. Through on-site observations and physical assessments, façade characteristics, spatial organisations, structural elements, building materials, and their relationship with the surrounding environment were systematically examined and documented.

The data obtained were analysed within the framework of energy-efficient passive design principles. The buildings were evaluated according to criteria such as settlement layout and orientation, building form, spatial organisation, building envelope characteristics, material use, and construction techniques. As a result of the evaluation, it is aimed that the energy-efficient passive design strategies adopted in traditional Ayvalık houses will both contribute to the restoration processes of the structures and guide the designs of new houses to be built in similar climate regions.

This paper constitutes the initial phase of a long-term research study. The data collected in this phase will be used to assess the energy performance and carbon emissions of Ayvalık houses. Following the current condition analysis, improvement scenarios based on existing usage patterns will be developed, and the integration of active energy systems will be explored. Both passive and active design strategies will be assessed across various scenarios, and benefit analyses will be conducted to identify optimal solutions. Improvement strategies applied to different building typologies will be supported through deep learning algorithms. As a result, an energy-efficient decision support system will be developed to guide the restoration and adaptive reuse of traditional buildings. All phases of the study are illustrated in Fig. 1., with the current phases addressed in this paper highlighted.

2.1. Case Study

Ayvalık district of Balıkesir is located in the south of Edremit Gulf, opposite the island of Midilli, between bays and gulfs. The settlement is concentrated in low-slope coastal areas, while its surroundings are characterized by gently elevated hilly terrain. According to the TS 825:2024 standard titled Thermal Insulation Rules for Buildings, Ayvalık is located within the 3rd-degree day zone and is classified as a temperate climate zone (Fig.2.).

Following the migration of the Greek population in the 18th century, Ayvalık emerged as a significant commercial center. This period of development was also evident in the city's architectural development (Ozker, 2020), marked by an increase in religious buildings, educational institutions, and examples of civil architecture. The increasing population and urban expansion, particularly from the mid-1950s onward, further accelerated Ayvalık's development. To control urban growth and protect the existing architectural character, the High Council of Immovable Monuments and Antiquities declared Ayvalık a historical and natural conservation area in 1976 (ÇEKÜL Foundation, 2014).

Within the scope of this study, traditional houses located in the city center of Ayvalık—structures that have largely retained their original architectural features—were selected for analysis. The selection criteria included the registration status of the buildings, the preservation of original materials and structural characteristics, representation of different plan typologies, and their continued functional use today

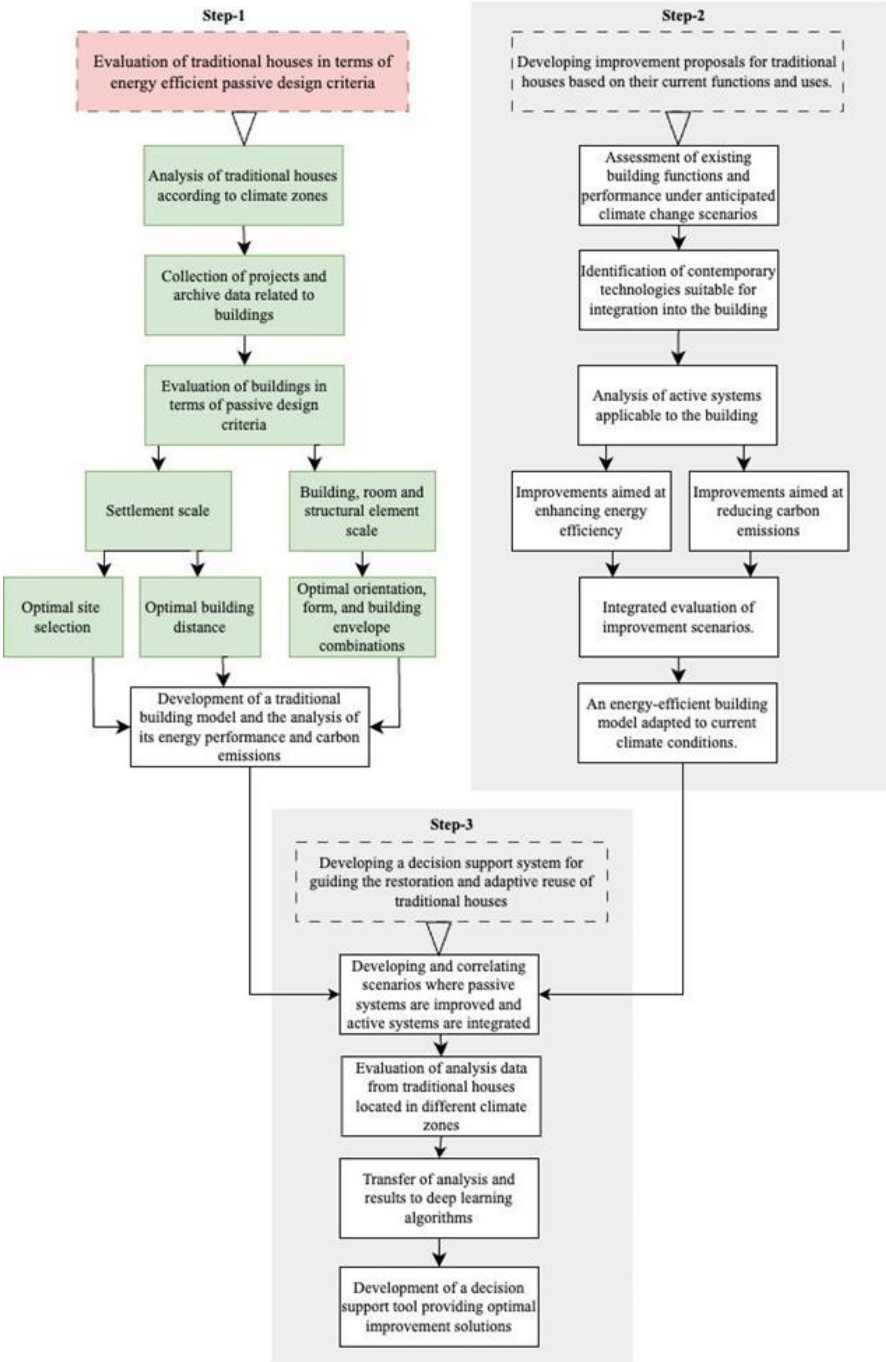


Fig. 1. Schematic representation of the study

2.2. Traditional Ayvalık Houses

Traditional Ayvalık houses, which played a significant role in shaping the historical urban pattern, are still in use today and meet a significant portion of the city's residential needs. These houses, typically arranged in a contiguous row typology, are characterized by their street-facing entrances and stone masonry construction, rising up to three stories, and they have back courtyards. Constructed by Greek craftsmen, these houses generally feature workshop or commercial spaces on the ground floor, while residential areas are located on the upper floors. One of the most distinctive architectural features inherited from the Greek period is the entrance design: doors are recessed within niches or iwans, opening directly to the street and typically accessed via two or three steps (Akın, 2015).

The spatial organisation of the streets and the layout of the dwellings reflect the prominence of neighbourhood interactions. Architectural elements such as bay windows 'cumba', balcony, and terrace projections contribute not only to social engagement between neighbours but also to natural ventilation and interior comfort. These characteristics feature the multifunctionality of Ayvalık houses, which historically served both residential and productive purposes while fostering social ties within the community.

Fig. 2. Degree day regions map of Turkey (TS 825:2024)

3. Passive Design Strategies in Traditional Ayvalık Houses

Under this heading, traditional Ayvalık houses were systematically examined with reference to energy-efficient passive design criteria. The analysis focused on parameters such as settlement area and building orientation, building form, spatial organization, building envelope, and material selection. This analysis sought to identify the relationship between the traditional housing fabric and energy-efficient principles.

3.1. Settlement Area and Orientation

The settlement of Ayvalık is concentrated along the coastline, in low-sloping areas. According to TS 825, Ayvalık is located within the third-degree day zone and classified as a temperate humid climate region. The dominant wind direction in the region is from the northeast. These northeasterly winds enhance thermal comfort during the summer months by providing a cooling effect. In addition, local breezes—such as the "meltem" winds caused by land-sea temperature differentials— contribute to the region's climatic comfort.

Fig. 3. The street pattern of traditional Ayvalık houses (Personal archive, 2015)

Fig. 4. Building heights and street widths (Personal archive, 2024)

The city's grid plan offers several environmental advantages, such as benefiting from the dominant winds and increasing sea access. Fig. 3 shows the grid system, the positioning of the buildings relative to the sea and the building blocks. Streets are narrow, effectively channelling airflow from the sea inland. Buildings are arranged close to one another, providing mutual shading and promoting air circulation.

This settlement organisation supports passive energy strategies by facilitating natural ventilation, providing solar control and contributing to thermal comfort at both the building and urban scales (Fig. 4). In this context, the settlement pattern and orientation of structures in Ayvalık exemplify climate-responsive urban design principles that are inherent in traditional settlements.

3.2. Building Form
Traditional Ayvalık houses are generally arranged in a contiguous layout, with their entrances positioned according to the street. These buildings are typically constructed with a maximum of three stories, adopting a typology characterised by 'cumba' and back courtyards, and are built using local stone materials. These houses are generally rectangular in plan and feature two façades—one facing the street and the other facing the back courtyard or garden. Windows and openings placed in alignment across opposing façades facilitate cross ventilation, thereby enhancing natural airflow and mitigating interior humidity. Architectural features such as balconies, terraces, overhangs, and notably bay windows of varying dimensions are prevalent. These elements not only foster social interaction within the urban pattern but also serve essential passive energy functions, including shading and ventilation. The overall architectural approach demonstrates an adaptive response to the temperate humid climatic conditions of the region while accommodating the socio-cultural practices of its inhabitants. As such, traditional Ayvalık houses exemplify vernacular architecture that successfully integrates user comfort with passive energy efficiency strategies.

3.3. Spatial Organisation
Traditional Ayvalık houses are typically two- or three-story structures, with one or two levels constructed above the ground floor. Based on their floor area, these houses can be classified into three categories: 40–50 m², 80–90 m², and over 120 m². One of the most distinctive architectural features inherited from the Greek influence is the design of the entrances—positioned within niches and iwans, opening directly onto the street, and accessed via two to three steps (Akın, 2009).

The ground floors are designed independently from the upper floors in terms of both function and spatial organization. The plan scheme is formed according to the formation of spaces on the upper floors and functional diversity on the ground floors. While the upper levels accommodate residential functions, ground floors were traditionally allocated for commercial or service-related uses, such as workshops, ateliers, or storage spaces. The absence of residential functions on the ground floor is due to its design for commercial activities.

In some cases, ground floors also include courtyards; however, due to the compact and contiguous building layout, courtyards are not present in every house (Yıldırım Gönül, 2004). Given that all traditional Ayvalık houses have a street-facing orientation, access to these courtyards is generally provided through the house.

Living areas are typically located on the first floor (Yıldırım Gönül, 2004). This floor, which is accessed via stairs leading from the ground level, typically contains two or three rooms. In accordance with traditional housing typology, there is no distinct room designated exclusively for the kitchen; instead, the kitchen is often integrated into the main living area. Many houses also feature internal doorways connecting adjacent rooms, facilitating movement and interaction between spaces.

Sleeping areas are usually situated on the second floor, which often includes enclosed projections such as bay windows that extend toward the street (Yıldırım Gönül, 2004). These architectural elements provide several advantages, including spatial expansion, enhanced views, and improved natural ventilation. At the same time, terraces are frequently used on this floor.

Fig. 5. Spatial organisation according to floor plans in Ayvalık houses Plan drawings (Ozker, 2020)

3.4. Building Envelope

The building envelope—including the roof, walls, floor, windows, and doors—constitutes the surface controlling heat transfer between indoor and outdoor environments. The thermal transmission occurring through these components influences both indoor air temperature and interior surface temperatures.

3.4.1 Walls

The ground-floor exterior walls of traditional Ayvalık houses are composed of load-bearing masonry stone walls, approximately 60–70 cm thick. The most commonly used material on this floor is a natural, volcanic-origin stone locally known as “sarımsak taşı” (sarımsak stone). In buildings where this material was not employed, rubble stone walls were constructed instead. Typically, walls were built with stone up to the level required to support wooden beams, while the uppermost courses were completed using brick (Efe, 2019).

In structures utilizing sarımsak stone, the exterior surfaces were often left unplastered and unpainted in order to preserve the natural appearance of the stone. In contrast, the rubble stone walls were generally plastered and painted on the exterior surfaces. On the upper floors, the material composition of the exterior walls changes. In some buildings, stone was continued through the first and second floors (Fig.6; a,b,c); however, in most cases—especially in projecting sections such as overhangs—the Bağdadi construction system was applied (Fig.6. d,e). Bağdadi walls were formed by filling a timber frame with brick infill and then plastering the surface (Efe, 2019; Çamkaya, 2023). Fig. 6 illustrates the exterior wall layers observed in traditional Ayvalık houses.

There is also observe variation in the interior wall construction depending on the floor level and construction period. On the ground floor, earlier examples often used the Bağdadi system for partition walls, whereas in later periods, the use of stone or solid brick became more widespread (Uztuğ, 2006). On the upper floors, interior partitions were typically constructed using the Bağdadi technique, with wall thicknesses ranging from 12 to 15 cm. Regardless of the material used, all interior wall surfaces were plastered to achieve a smooth surface.

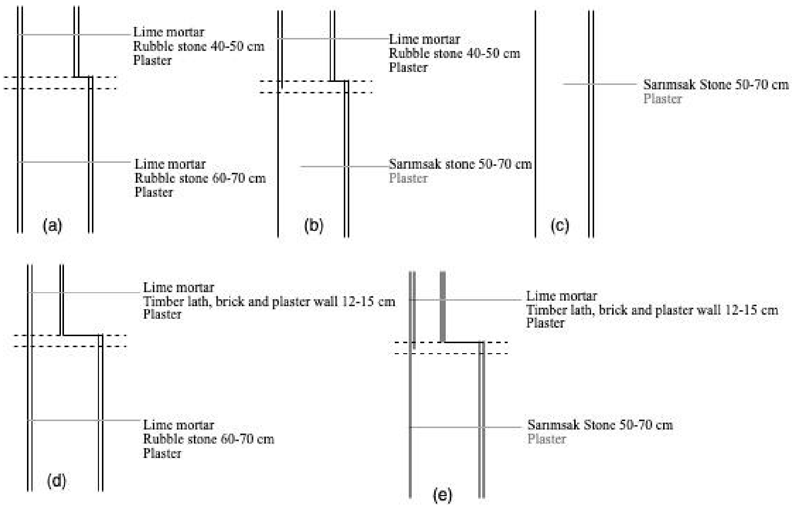


Fig. 6. Layers of walls in traditional Ayvalık houses (Created by the author)

3.4.2 Windows and Doors

In traditional Ayvalık houses, doors and windows are designed in response to climatic conditions. To address the challenges of the temperate humid climate, and to ensure adequate daylight and natural ventilation within the interior, window openings were designed to be relatively large, and storey heights were left high. These design strategies facilitated both air circulation and the entry of sufficient heat and light into the indoor environment (Akın, 2015).

Analysis of the size and positioning of the windows reveals that, on the ground floors, only small openings are typically placed on the street-facing façades. Also, small ventilation openings are located above the entrance doors. Ground-floor spaces are equipped with smaller windows compared to the upper floors, generally measuring approximately 70–80 cm in width and 130–140 cm in height (Çamkaya, 2023). By contrast, the upper-floor windows were designed in larger dimensions, ranging between 80–100 cm in width and 150–180 cm in height, with aspect ratios varying between 1:1.5 and 1:2 (Çamkaya, 2023). These wide upper-floor windows enhance ventilation during summer months and optimize solar heat and light gain in winter due to lower solar angles. Fig. 7 illustrates the ground-floor openings, the rectangular windows on the first and second floors, and the shutter serving as solar shading devices.

Windows and doors feature timber frames with single glazing. This system contributes positively to passive indoor climate regulation due to the limited occurrence of thermal bridging. In three-story buildings, timber shutters installed on the top-floor windows serve to control direct solar radiation and reduce indoor heat gain. Doors are generally situated within recessed iwans and are constructed as double-leaf timber joinery. Their dimensions range from 100 to 250 cm in width and from 220 to 350 cm in height (Efe, 2019).

Fig. 7. Building facades (Personal archive, 2024)

3.4.3 Roof

In traditional Ayvalık houses, the roof system consists of gable or hipped roofs constructed with wooden structural frameworks and covered with alaturka tiles (traditional material) (Uztuğ, 2006). The form of the roofs is significantly influenced by the contiguous row-house typology. The parapet walls separating the roofs of adjacent buildings were generally constructed using solid bricks (harman tuğlası) (Çamkaya, 2023). These elements served not only as a fire safety measure but also as a means of defining spatial boundaries between roofs. The use of alaturka tiles was particularly suited to the local climate. The air gaps between the overlapping tiles contributed both to waterproofing and to passive ventilation. The structural framework of the roofs consists of timber elements from locally sourced materials. The roof spaces formed by sloped roofs play a passive climatic role by reducing thermal load on upper floors during summer and minimizing heat loss in winter.

Additionally, the roofs were designed to collect rainwater. Rainwater collected on the roof is channeled through pipes 'künk' to cisterns located either on the ground floor or within the courtyard (Çamkaya, 2023). These cisterns store rainwater collected during the wet season, meeting household water needs throughout the year. Moreover, the thermal mass of the water within the cisterns contributes to maintaining indoor thermal comfort, helping keep interiors cool in summer and warm in winter (Efe, 2019).

3.5. Materials

In traditional Ayvalık houses, locally sourced and natural materials—primarily various timber species and volcanic stones from the region—were used extensively. Among these, a volcanic-origin stone known colloquially as sarımsak stone is particularly prominent (Efe, 2019). This stone was used both as a load-bearing material in wall construction and as a decorative element around building corners, window, and door frames. In addition to sarımsak stone, rubble stones were frequently used in masonry walls. In the construction of bay-windowed exterior walls and interior partition walls, a timber-frame (Bağdadi) system with brick infill (harman tuğlası) was commonly employed. The interior components of the buildings were also predominantly crafted from timber. Stairs, built-in cabinets (yüklük), closets, door and window frames, and shutters were all made from timber (Çamkaya, 2023). The primary load-bearing floor beams were also wooden—typically made from cypress—and measured approximately 25–30 cm in width. In addition to the main structural materials, natural binders such as earth mortar, lime mortar, and clay were used both as binding agents in masonry and as plaster coatings.

Furthermore, wrought iron elements (ferforje) are commonly observed on building façades. Although originally installed for security purposes, their fine craftsmanship elevated them into significant aesthetic features, particularly when used on doors, windows, bay windows (cumba), and balcony railings.

4. Results

The study systematically presents the energy-efficient design strategies in traditional Ayvalık houses. The passive design criteria identified in these structures are compiled and summarised in a schematic table (Fig. 8).

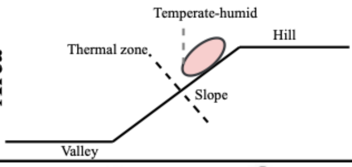
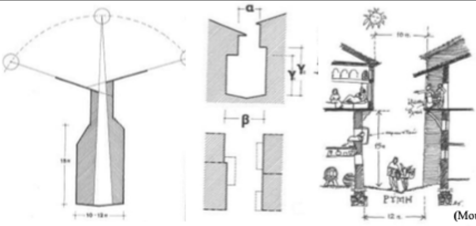
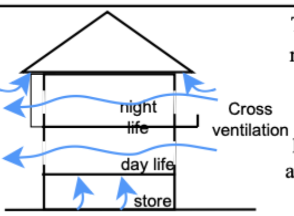
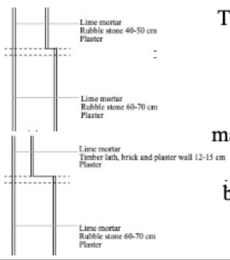
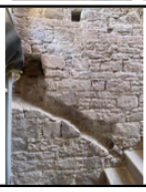
Settlement Area		In temperate humid climate regions, settlements are typically located on sloped terrains. However, in Ayvalık houses, the settlement is situated on flat coastal land. This configuration has been shaped by the topographical characteristics of Ayvalık and the socio-cultural needs of its users.
Distance between Buildings	 (Moutsopoulos, 1974)	In the traditional houses of Ayvalık, narrow streets were designed to obstacles to solar irradiation, thereby creating shaded outdoor spaces. Additionally, these narrow street patterns facilitated the channelling and velocity of wind flow, contributing to improved microclimatic comfort within the urban fabric.
Building Form		In temperate humid climate regions, typically characterised by expansive surfaces oriented toward prevailing winds and featuring rectangular or irregular plan forms. Traditional Ayvalık houses, however, are arranged in rows with openings predominantly located on their narrow façades. Architectural elements such as 'cumba' and balconies provide natural air flow to the structure.
Natural Ventilation		To reduce the adverse effects of humidity in traditional Ayvalık houses, natural ventilation strategies were employed. Large, opposing windows were incorporated to facilitate cross-ventilation, while architectural elements such as 'cumba' and balconies enhanced airflow by directing prevailing winds into the interior spaces. The roofs were designed with a pitched form and covered with clay tiles, which contributed to passive ventilation through the air gaps between the tiles.
Building Envelop		The structural components of traditional Ayvalık houses are composed of natural materials, and their combination in forming the building envelope is well-adapted to the local climatic conditions. In ground flooring, the use of stone walls and enhanced structural durability contributes to thermal comfort by maintaining interior coolness. In some cases, 'baghdadi' (timber frame infill) wall systems were utilised on upper floors and stone walls were applied in some buildings. The materials used for roofing and window openings were also found to be compatible with the region's climatic requirements.
Sunlight Control		Traditional Ayvalık houses benefit from controlled solar irradiation due to the narrow layout of their streets. Additionally, timber shading elements have been incorporated into some buildings to prevent direct sunlight from entering interior living spaces.
Water Management	 A view of the pipes coming from the roof on the wall.	In traditional Ayvalık houses, rainwater is collected and stored by transferring it to cisterns located on the ground floor or in the atrium with pipes.
Fire Safety		Due to the row-house configuration of traditional Ayvalık houses, brick firewalls are constructed between adjacent units to enhance fire safety and prevent the spread of fire between structures.

Fig.8. Passive design features of traditional Ayvalık houses

5. Conclusions

The spatial organization, material usage, and construction techniques of traditional houses are shaped by the geographic characteristics, climate conditions, and socio-cultural structure of their respective regions. In this context, traditional Ayvalık houses exemplify climate-responsive architecture, where passive design principles have enabled the construction of environmentally adapted buildings that enhance user comfort.

This study presents a systematic evaluation of traditional Ayvalık houses in terms of energy-efficient passive design criteria. The assessment framework includes settlement area, building orientation, building form, spatial organization, building envelope, and material usage. The analysis revealed that narrow streets were deliberately formed to benefit from natural ventilation and limit solar radiation. Building orientation was aligned with prevailing wind and sunlight conditions. The rectangular building forms reflect adaptation to the temperate humid climate. Moreover, overhangs and cumba elements were observed to reduce the impact of high humidity. An examination of plan typologies indicates a frequent use of open spaces such as courtyards, balconies, and terraces. The functional organization typically places workspaces on the ground floor, living areas on the first floor, and bedrooms on the second floor. While this arrangement is largely driven by social customs, locating living spaces on the middle floor also contributes positively to thermal comfort.

The evaluation of the building envelope shows that wall layers are designed to suitable climatic conditions and minimize heating and cooling loads. The size and placement of window openings promote natural airflow, while pitched roofs provide summer cooling and reduce heat loss in winter. The use of local and natural materials is crucial for minimizing carbon emissions. Stone masonry on the ground floor enhances structural stability, regulates humidity, and contributes to thermal comfort. The upper floors often employ the Bağdadi wall system, which reduces structural weight and supports natural ventilation and humidity control. Timber-framed windows and floor systems offer low thermal conductivity and partial permeability, enhancing both insulation and ventilation.

The study demonstrates that traditional Ayvalık houses with passive design principles reflect an inherently energy-efficient design approach. However, contemporary architectural practices often fail to integrate such climate- and environment-sensitive parameters. Incorporating the passive strategies used in traditional Ayvalık houses into modern design processes offers valuable opportunities to improve energy efficiency and reduce carbon emissions. Decisions at the settlement scale that enable natural ventilation, choices related to building form, material selection, and the layered structure of the building envelope can play a significant role in reducing heating and cooling demands. In particular, designing climate-adaptive building envelopes can substantially enhance overall energy performance.

This study provides a systematic evaluation of energy-efficient passive design strategies in traditional Ayvalık houses. Investigating these buildings, many of which are registered and well-preserved, establishes a foundation for future research in the field of energy performance in vernacular architecture. Moreover, the study offers passive design recommendations that can inform both the evaluation of traditional buildings in similar climate zones and the enhancement of energy efficiency in contemporary building design.

To expand and improve upon this research, the following future work is proposed:

- Experimental studies can be conducted to determine the physical properties of the traditional materials used in Ayvalık houses. These studies can generate reference data for use in building energy simulations by identifying the materials' optical and thermophysical properties.
- While this study has compiled the passive design principles observed in traditional Ayvalık houses, further work can investigate the integration of passive and active systems based on current building functions and usage needs.
- Energy-efficient retrofit scenarios developed for traditional houses can be supported and promoted in restoration and implementation processes.
- Carbon emission analyses can be conducted on traditional buildings in use, with improvement proposals developed to reduce emissions.
- Simulation-based studies can explore how energy-efficient approaches derived from traditional houses can be adapted to contemporary buildings.
- The potential performance of traditional buildings under future climate change scenarios can be analyzed, and climate adaptation strategies can be developed accordingly.

In conclusion, this study on the energy efficiency of traditional houses provides a reference not only for researchers in building physics but also for those working in restoration, materials science, architectural design, and practice.

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Material assessment in tiny houses: comparing the embodied carbon and circular potential of steel and timber

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Abstract. Tiny houses have emerged as a potential, environmentally friendly housing solution to mitigate the unsustainable impacts of the residential sector. Their popularity has increased significantly, especially during the COVID-19 pandemic. With their growing appeal, the building performance, sustainability, and circularity of various materials in tiny houses are worth to be search. This study focuses on the performance characteristics of the most commonly used architectural materials in tiny house models, steel and timber, to assess the relations with CO_2 emission, energy use, and circularity. A prototype tiny house, located in a temperate climate zone (Mersin, Turkiye), is modelled in Autodesk Revit using steel and timber material configurations for walls, floors, and ceilings. The energy consumption and carbon emission of these two cases are analyzed using Autodesk Insight in conjunction with Revit software. For the circularity evaluation of the cases, the Material Circularity Indicator (MCI) tool is used. The findings reveal that using timber for wall, floor, and ceiling elements in tiny houses has better embodied carbon emissions than steel. The embodied carbon emissions of a steel-based tiny house exceed those of a timber-based counterpart by 30%. However, from the circularity perspective, steel has a higher circularity index with an 82% ratio than timber with 52%. Consequently, the environmentally friendly buildings are not only related to carbon emissions or energy consumption but also related to waste disposal reduction and, accordingly, circularity.

Keywords: Tiny houses; Circularity; Carbon emission; Energy use; MCI.

1. Introduction

In the late 1990s in the United States, due to housing affordability issues and a desire to live more sustainably, the tiny house movement emerged by building very small homes (Shearer et al., 2018). The idea behind this movement is mainly to cope with economic challenges and to reduce the consumption of natural resources to be sustainable and energy efficient (Saleem et al., 2021). The 'tiny house' or 'tiny home' is defined as a small dwelling unit less than 37 m^2 that is either permanent or relocatable by the 2018 International Residential Code (IRC) (Kuittinen et al., 2023). A typical tiny house layout features a compact kitchen, a bathroom, a combined living and working area, and a sleeping space, with very limited storage capacity. Vaulted ceilings are often used to maximize vertical space, and sleeping lofts are commonly incorporated into the design (Mukhopadhyay, 2020).

There are many benefits to living in a tiny house and reducing the size of the living space. One of the biggest benefits of living in a tiny house is the reduction of the carbon footprint (Wu and Hyatt, 2016). Although in Boeckermann et al.'s (2019) questionnaire study, the most distinct reason to live in a tiny house is seen as affordability, the environmental impact of tiny houses is another important key driver (Kuittinen et al., 2023).

Buildings consume over 40% of global energy, generate 36% of all carbon dioxide (CO_2) emissions, and 28% of greenhouse gas emissions (Rauf et al., 2022). Even though significant improvements in energy efficiency have been achieved in recent decades, population growth (supposed to grow by 29% until 2050) and the increasing need for residential areas cause a rise in energy demand (Crawford and Stephan, 2020). The energy demand and greenhouse gas emissions are influentially related and so, high energy use causes unfavorable environmental impacts (Jin and Kim, 2018; Sabobeh et al., 2024). In this regard, the studies (Carlin, 2014; Kilman, 2016; Crawford and Stephan, 2020; Sabobeh et al., 2024) claim that tiny houses reduce the material demands, create a lower environmental impact in terms of resources and production process. Unlike traditional residences, tiny houses consume less energy for heating, cooling, and lighting. Yet, the selection of the building materials plays a crucial role in evaluating a buildings' environmental impacts (Dipasquale et al., 2025). In other words, the materials

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used in the design of tiny houses affect the carbon emissions and energy use. Commonly used material for these houses is wood. However, owing to some advantages like being lighter, fire-resistant, etc., steel is also used for the tiny houses.

Among sustainability approaches, circular economy (CE) has attracted great attention in recent years and this interest has significantly influenced design processes, especially with circularity-focused approaches (Ruiz-Pastor et al.,2024). The primary goal of evaluating the circularity of products is to aid decision-making by offering insights regarding the products and their life stages (Bragança et al., 2010). Additionally, the assessment needs to be coherent, comprehensive, and objective (Mesa et al., 2018; Ruiz-Pastor et al.,2024). The primary additive of the circular economy is made "sustainability more likely" by separating economic development and resource consumption (van den Berg, 2019). On one hand, adopting circular economy (CE) practices is increasingly recognized as contributing to sustainable development goals (Schroeder et al., 2019). On the other hand, circular economy and sustainable development are not systematically synonymous because the recycling process can create new challenges for overall environmental impacts, while it is one of the main opportunities in circularity. However, to understand the relation of circularity and sustainability still needs further research (Schroeder et al., 2019).

In this regard, the aim of this study is to investigate the triple relation between carbon emissions, energy use, and circularity through a tiny house. The objectives of the research are (i) to compare the carbon emission and used energy intensity differences of timber and steel wall, floor, and ceiling elements in tiny houses, (ii) to calculate the circularity index of timber and steel materials wall, floor, and ceiling elements in tiny houses, and (iii) search the environmental impacts of CE work toward sustainability.

2. Materials and Method

In this research, a tiny house with two alternatives, timber-based and steel-based, is modelled in Autodesk Revit as a case study. The tiny house has a floor area of 18,85 m^2 and a loft area of 4,5 m^2, including open living space with a kitchenette, a bathroom, and a loft that serves as a sleeping space, and a closet. The height of the highest point of the house is 4.20 meters, and the height of the lowest point is 2.70 meters. The plan layout and 3D view of the tiny house are illustrated in Fig. 1. The first alternative model is built from wood and has a wooden joist for the floor and ceiling. The wall frames are created with C16 timber stud (75x125 mm) and covered with wood-based MDF material. The second alternative model is made from steel material. For ceiling and floor elements are designed with steel joists. The wall frames are formed with steel studs and covered with gypsum board. The material details in two alternatives are seen in Fig. 2.

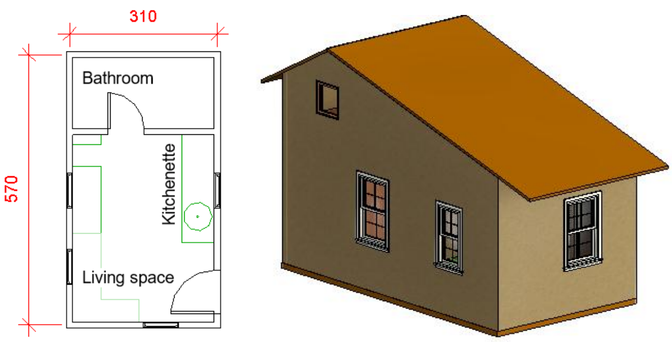

Fig. 1. Tiny house case study floor plan and 3D view

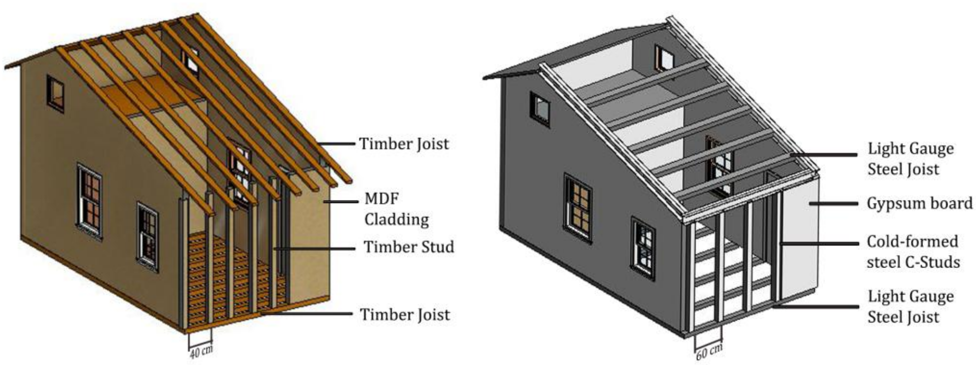

Fig. 2. Two alternatives with timber and steel material-based tiny houses

In the light of the scope of the study, the embodied carbon, operational carbon, energy used and circularity ratios for timber and steel tiny houses are calculated. In light of the scope of the study, the embodied carbon, operational carbon, energy used, and circularity ratios for timber and steel tiny houses are calculated. The tools used are explained in the following sections.

2.1. Carbon Emissions and Energy Use Intensity Calculations in Next Gen Insight

Assessing the carbon impacts of timber and steel tiny houses, two alternatives are simulated by utilizing Autodesk Insight. The scope of Insight covers the envelope and interiors subset of architectural elements based on the data included in the Energy Analytical Model. Therefore, the walls, ceiling, and floor elements are the focus of this research. Moreover, embodied carbon emission calculation in Insight comprises only the manufacturing stage (A1-A3) while the operational carbon emissions include operational energy (B6). Hence, the embodied carbon in this study refers only to the manufacturing stage, and operational carbon represents the operational energy phase.

Insight is a cloud-based tool that connects with Revit, providing users with flexible dashboards, an intuitive interface, and an easy analysis approach. The interface of Insight makes it more practical to explore, visualize, and compare carbon analysis results. It relies on Revit's Energy Analytical Model as its foundation for Operational (OC) and Embodied Carbon (EC) analysis. Insight uses the stored data in Revit, like building envelope performance, material specifications, etc., and more to illustrate the relation between carbon impacts and energy offsets (Insight Product Team, 2024).

The Revit Energy Analytical Model offers a reliable foundation for evaluating both Embodied and Operational carbon analyses. The Embodied Carbon analysis in Insight leverages data from Building Transparency's EC3 database regarding material Embodied Carbon and provides the option to modify these defaults or incorporate specific EC definitions. For Operational Carbon, Insight uses EnergyPlus, an extensively used open-source simulation engine for energy analyses. This engine is developed by the US Department of Energy (DOE), managed by the National Renewable Energy Laboratory (NREL), and applied worldwide for dynamic energy simulations (Insight Product Team, 2024).

2.2. Circularity Calculations in Material Circularity Indicator (MCI) Tool

For the evaluation of the circularity indexes of timber and steel tiny houses, Material Circularity Indicator (MCI) tool is used in this study. The Material Circularity Indicator (MCI) is a free Excel tool that measures the circularity of a product's material flow. The MCI is one of the circularity metrics that meets the guidelines of the new ISO 59020 standard for 'Circularity Metrics'. Circularity metrics provide a superior assessment compared to solely depending on recycling rates, as they encompass all methods of attaining circularity, including consumption avoidance, durability enhancement, reuse, remanufacturing, bio-based products, and composting.

The MCI tool can be used to evaluate and compare the 'circularity' scores of individual goods and product portfolios. The MCI quantifies the circularity of a product, namely the extent to which it has separated from the use of non-renewable resources and the generation of unrecoverable trash. The calculator assesses a product's circularity using the modified 2024 MCI methodology, delivering a score ranging from 0 to 100%. A score of 0 implies a standard linear model based on consumption and disposal. A 100% score, on the other hand, represents a fully circular strategy in which the product avoids the use of nonrenewable resources and eliminates waste entirely (URL-1, 2025).

3. Results and Discussion

In this section, the quantitative results are generated and interpreted to assess the sustainable performance of products from a circularity perspective. First, the carbon footprints of tiny houses are calculated in Insight. Second, the circularity ratio of them is computed. Finally, the results are compared and used to try to solve the relationship between carbon emissions and circularity.

As a first step of the study, carbon emission calculations are carried out. Before simulating the carbon emissions in Insight, some necessary parameters should be specified in the energy settings in the Revit interface because Insight uses data in the energy analytical model. Under the advanced energy setting tab in Revit, building function is selected as single house, building operating schedule is set 24/7, HVAC system is arranged Central VAV, HW Heat, Chiller 5.96 COP, Boilers 84.5 eff. The geographic location of the project should also be clarified before the analysis. In this study, Mersin is selected as the location of the tiny houses. Then, an analytical model is generated and uploaded to the Insight. The model is analysed in the cloud for key sustainability and performance aspects of the houses. The results are seen in the cloud web page. The outputs from the analysis are shown comparatively for timber and steel tiny houses in Fig. 3.

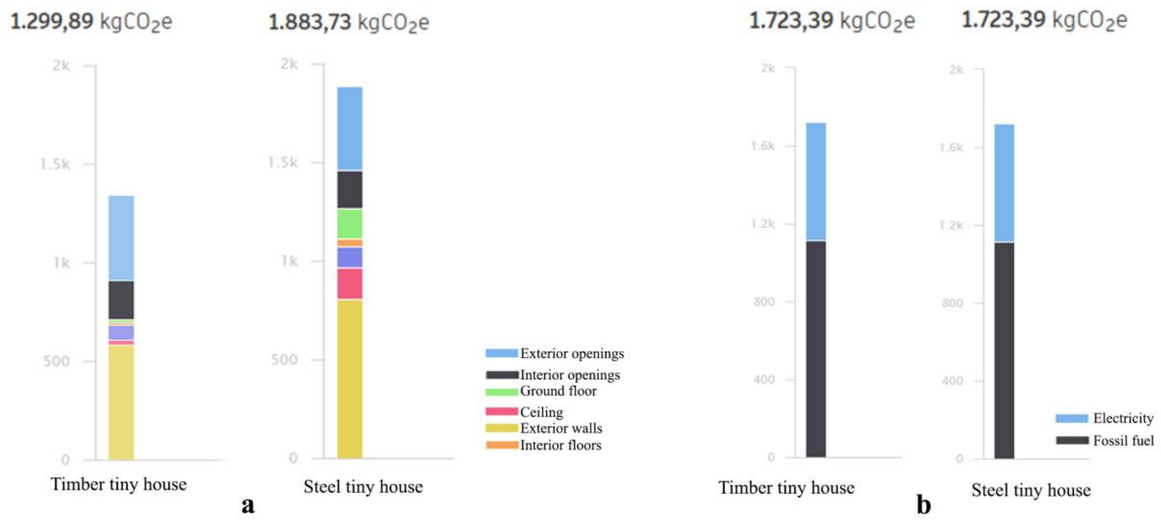

Fig. 3. (**a**) Embodied carbon emissions and (**b**) operational carbon emissions of timber and steel tiny houses

According to the calculation results, timber-based tiny house has lower embodied carbon emission with 1299,89 kgCO2e, while steel-based tiny house has 1883,72 kgCO2e embodied carbon emission. The operational energy of tiny represents their total energy demand to operate building systems, determined through analysis of fossil fuel types and electricity data. Therefore, operational energy is not related to the type of materials used for the building elements. Thus, the operational energy of the two alternatives, which are exactly the same each other except for building materials, is observed to have the same value. Accordingly, annual energy use intensity, an indicator of the energy efficiency of a building's design and/or operations, should be the same for the two alternatives. The energy consumption of these houses is 274,79 kWh/m², which represents the amount of total energy used in one year divided by the building area. When considering the amount of energy for individual heating is 311 kWh/m2 in Turkey's capital Ankara (Ucal and Günay, 2021), the energy use of tiny houses for heating, cooling, and electricity is considered reasonable.

The second step of the study is getting the circularity ratios of the two alternatives. For the calculation, selected material types and their used amounts are taken into consideration. The quantity and mass of each component are specified. The source of the materials for each component is added under the resource inflow. In this tool, the source of the materials can be chosen as virgin, recycled, remanufactured, or reused. In this study, the source of each material is designated as virgin. Besides, it is indicated how many functional units the components deliver over their life versus the industry average. Here, the industry average is '1' while the steel elements are defined as '6', and timber elements are '2'. Then, for the circularity calculation, the end-of-use conditions of each product should be clarified. For the steel alternative, resource outflow is defined as reuse, and for the timber alternative, it is defined as recycling. According to these inputs, the calculator tool gives the circularity results seen in Table 1. This table includes inputs provided by users and outputs, highlighted in the table, generated by the calculator tool. The tool gives the circularity index result between 0 and 1, circularity index percentage between 0% and 100%, also produces circular mass and linear mass results.

Table 1. Circularity results of timber and steel tiny houses generated in MCI tool

	Component Name	Mass Each	Quantity	Resource Inflows			Utility Unit		Utility Function	Resource Outflows				Comprised of				Circular Mass	Linear Mass
		Kilograms		Material Type	Source	Utility Based on	U	U(av)		Collection Rate	Destination	(0-1) MCI	% MCI	Raw material Decoupling	Waste Decoupling	Enhanced Utility	Circularity Gap	kg	kg
STEEL TINY HOUSE	Cold Formed Steel C-stud	3,78	30	Steel	Virgin	Utility	6	1	6	100%	Reuse	0,93	91,7%	0%	50%	41,70%	8,3%	98,82	8,98
	Light Gauge Steel Floor Joist	16,85	15	Steel	Virgin	Utility	6	1	6	100%	Reuse	0,93	91,7%	0%	50%	41,70%	8,3%	231,66	21,06
	Light Gauge Steel Ceiling Joist	16,85	10	Steel	Virgin	Utility	6	1	6	100%	Reuse	0,93	91,7%	0%	50%	41,70%	8,3%	154,44	14,04
	Internal Gypsum Board	8,23	20,38	Gypsum	Virgin	Utility	3	1	3	50%	Reuse	0,78	75%	0%	25%	50%	25%	123,45	41,15
	External Gypsum Board	8,23	20,38	Gypsum	Virgin	Utility	3	1	3	50%	Reuse	0,78	75%	0%	25%	50%	25%	123,45	41,15
TIMBER TINY HOUSE	Timber Stud Wall Frame	1027,18	1	Timber	Virgin	Utility	2	1	2	100%	Recycle	0,57	52,50%	0%	5%	47,50%	47,5%	539,27	487,91
	Timber Floor Joist	397,82	1	Timber	Virgin	Utility	2	1	2	100%	Recycle	0,57	52,50%	0%	5%	47,50%	47,5%	208,86	188,96
	Timber Ceiling Joist	477,36	1	Timber	Virgin	Utility	2	1	2	100%	Recycle	0,57	52,50%	0%	5%	47,50%	47,5%	250,61	226,75
	Internal MDF Cladding	6,7	50	MDF	Virgin	Utility	2	1	2	100%	Recycle	0,55	50%	0%	0%	50%	50%	167,5	167,5
	External MDF Cladding	6,7	50	MDF	Virgin	Utility	2	1	2	100%	Recycle	0,55	50%	0%	0%	50%	50%	167,5	167,5

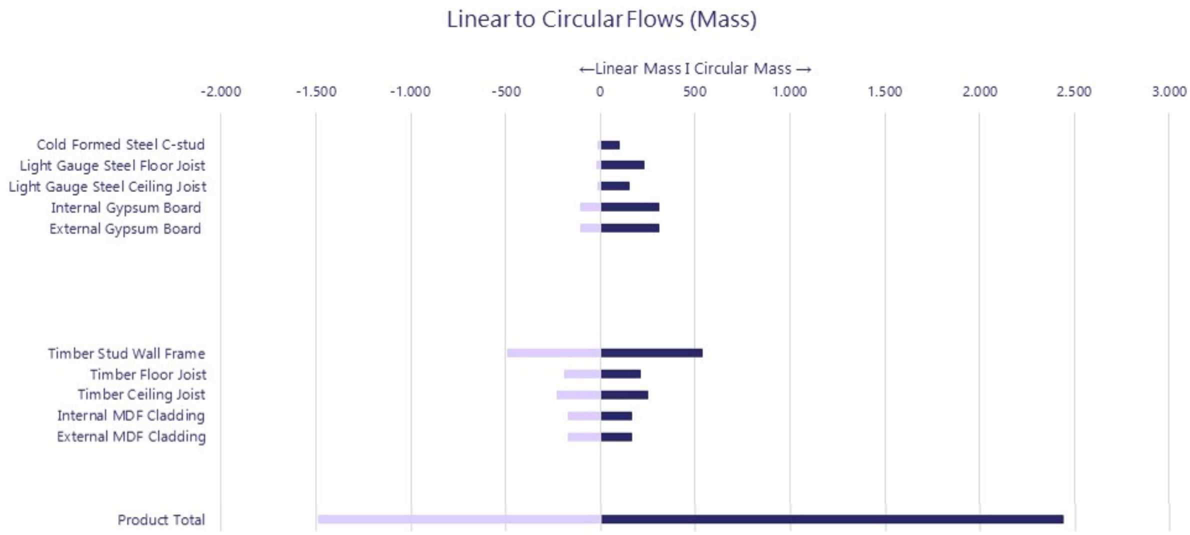

Fig. 4. Circular and linear mass distribution of the component, illustrating the proportion of mass considered circular based on total mass and circularity percentage

The circularity results demonstrated that the steel material tends to be more circular than timber. When compared to the linear and circular mass of the two alternatives, parallel to the circularity ratio, the circular mass of steel is higher than timber, as shown in Fig. 4. The circularity ratio strongly depends on the utility factors in the calculation. In the MCI tool, utility can also be chosen as lifetime, mass, lifetime &mass, utility &mass. In this study, it is defined as utility. Additionally, destination decisions, like reuse, recycle, compost, landfill, etc., and their rates affect the result of circularity. In this study, the destination decision for steel elements is defined as reuse with 100%, while for timber, it is recycling with 100%. In this regard, while steel is compared to timber, steel's strength-to-weight ratio is up to seven times greater, reducing the load on foundations. This efficiency leads to faster, more cost-effective construction. Steel can be reused repeatedly without losing integrity, and it is easy to disassemble steel frames. It is resistant to moisture-related problems and so does not require maintenance in a short period (Hradil et al., 2014).

As a result of the calculations, the circularity ratio of the steel tiny house is 81,5%, and the circularity ratio of the timber tiny house is 51,8%. From the perspective of the embodied carbon emissions releases, the timber tiny house has 30% less carbon emissions than the steel tiny house. At this point, only circularity or embodied carbon emission is not enough to say that one of the tiny steel or timber houses is the best option. The following Fig. (Fig. 5) provided by the MCI calculator helps to define components that you may want to prioritise for enhanced circularity due to their environmental footprint. Thus, the relation between circularity and carbon footprint can be interpreted.

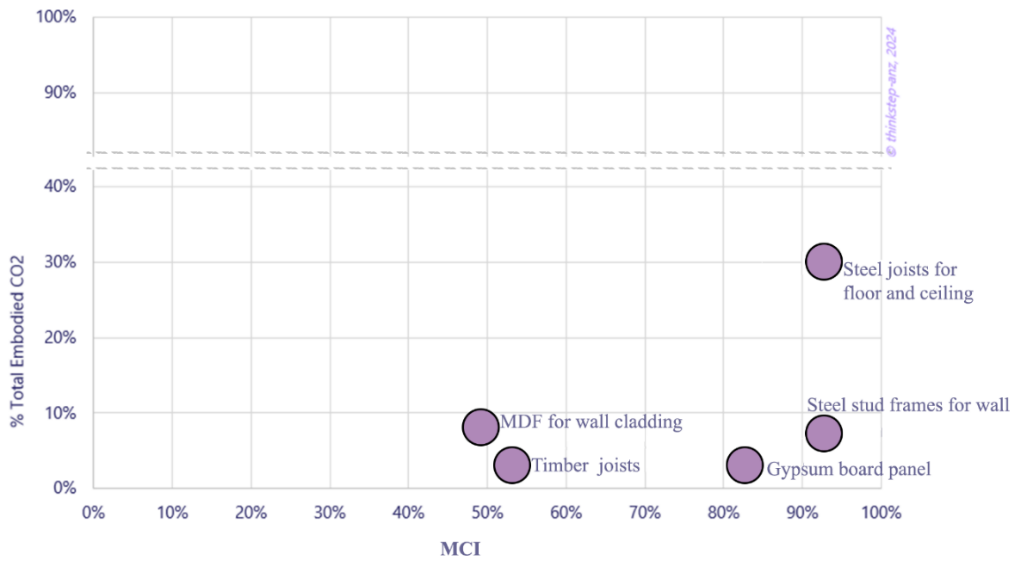

Fig. 5. % Circularity vs % Embodied CO_2 for timber and steel elements

4. Conclusions

Tiny houses are defined as affordable and environmentally friendly alternatives for the built environment, but the variety of materials used to produce these houses creates confusion and uncertainty. Although the dominant materials are seen as timber in the industry, steel also has a high usage ratio for the modular and tiny houses sector. In this regard, this study investigates the carbon footprint and circularity relations from the perspective of the environmental impact through a timber and steel tiny houses case project.

When the calculation results are evaluated directly, the embodied carbon of a tiny steel house is 30% more than tiny timber house. As a rapid evaluation, timber can be thought of as more logical to use for the sustainability goals. On the other hand, when examining the circularity results, the circularity ratio of the elements of the steel tiny house is 82%, while the circularity of the timber alternative is 52%. Moreover, considering the reuse potential of steel frames, steel can be evaluated as a more sustainable alternative than a timber house due to the reduction of waste generation and decrease in the use of raw materials. Consequently, sustainability has many inflows, and they show that there are additional factors for industry and owners to evaluate the environmental impacts of the housing design. As a result, this study does not provide a certain decision for the selection of material for tiny houses, as it can not be said that a timber tiny house or a steel tiny house is a preferable option for sustainable design. The embodied carbon of the steel tiny house is higher than timber, but maybe the environmental impact of the steel option can be balanced with the reuse of 5 or 6 times in its lifecycle. Ultimately, a truly comprehensive life cycle assessment should adopt a holistic perspective—one that not only considers the material production phase but also evaluates the potential for reuse, multiple life cycles, and recyclability beyond the initial end-of-life. Such an approach is essential for accurately assessing the long-term environmental performance of all types of buildings.

A limitation of this study can be specified that the operational carbon emission amounts and energy intensity used in the two alternatives are the same. For this reason, the operational energy cannot be an active input for the assessment of the environmental impacts of steel and timber tiny houses.

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Examination of green building certified "Haut Amsterdam" building in the context of sustainable building material selection criteria

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Abstract.
Today's environmental problems and limited natural resources have led the building sector to adopt more sustainable approaches. Sustainable buildings reduce energy and resource use, minimize environmental impacts and provide healthy living spaces for users. These buildings provide both environmental and economic benefits.

For this reason, it is of great importance to adopt sustainability principles in the building sector. Sustainability in the building industry can be achieved by selceting the right building materials and documenting them with green building certificates. By determining the criteria for the selection of building materials, it is possible to create user and environmentally friendly, long-lasting buildings. Buildings are certified and scored in many categories by green building certification systems. When these elements are considered together, it becomes possible to produce environmentally sensitive and efficient buildings.

In this study, the Haut Amsterdam building, which is certified as a green building and produced in line with sustainability targets, was examined in terms of its architecture, sustainable features and building material selection. It is aimed to evaluate the contribution of life cycle planning in the building and the use of building information modeling, and to evaluate the wood composite and aluminium materials used within the framework of building material selection criteria.

Keywords: Building Material Selection, Green Building Certification Systems, Building Life Cycle Assessment, Sustainability, Timber-Concrete Composite.

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1. Introduction

Today, sustainability-oriented approaches in the building industry have gained great importance both environmentally and functionally. Achieving sustainability goals in the building industry requires a holistic approach to building material selection criteria and green building certification systems. While the selection of the right building materials ensures that buildings have long-lasting, functional, environmentally friendly and economical features, the compliance of the selected materials with sustainability standards is documented through green building certificates. Green building certification systems aim to reduce the environmental impact of buildings based on criteria such as energy efficiency, material recycling and waste management. The integration of building material selection and green building certificates contributes to supporting building production processes that minimize environmental impacts and provide social benefits in the long term.

The choice of building material in buildings directly affects the building, the user and the environment. When making a choice, building materials should be selected that will increase building/user comfort, have a long service life, contribute to energy efficiency, are functional, can be integrated with the design and do not adversely affect human health and the environment with their life cycle (Sahlol et al., 2021). For this reason, it is aimed to select the most suitable option by creating various criteria in the selection of building materials, filtering and comparing according to the desired features.

The aim of this study is to determine the criteria to be considered in the selection of building materials in line with the principles of sustainable building design and to evaluate the building materials used in line with these criteria. In this context, the original materials used in the "Haut Amsterdam" building were evaluated and compared with common alternative building materials that can perform the same function within the scope of fire resistance, sound insulation, harmlessness to the environment and health, lightness, aesthetics, sustainability, ease of installation, long life and recyclability criteria. The evaluation of building materials was carried out using three

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different methods within the scope of Multi Criteria Decision Making- Line Graph Comparison method, Arıoğlu method and TOPSIS multi-criteria decision making method.

2. Building Material Selection Methods

The selection of building materials is a complex process that requires consideration of numerous criteria, including sustainability, cost, durability, and environmental impacts. To ensure that this process is managed in a systematic and objective manner, various selection methods have been developed. Some or all of these methods may be used (Balanlı, 1997). Some of these methods are summarized below.

The "Multiplicative Scheme" method proposed by Olssan and Perning enables the comparison of building materials evaluated from technical, structural, and economic perspectives and the elimination of options. In this method, each material type is scored using a multiplication factor based on its ability to meet the defined criteria, thereby supporting the selection process (Balanlı, 1997).

The "Hillerborg" is a method of analyzing products according to performance criteria and determining the most suitable option in terms of cost and quality. In this method, building material properties are defined and weighted. The quality values and costs of the options are calculated, and the data obtained is evaluated to determine the most suitable option (Balanlı, 1997).

The "Arıoğlu" method is a systematic, step-by-step decision-making method that manages the building material selection process. In this method, the following are determined in order: system level of expansion, environmental factors, functional requirements, objectives and constraints, material properties, and criteria. Options are identified by organizing material information. The identified options are evaluated, compared, and selected. Finally, a suitability check is performed (Kokulu, 2016).

The Multi-Criteria Decision Making method is an analysis technique that aims to systematically determine the most beneficial decision by evaluating multiple options based on technical, economic, environmental, and social criteria. In the preliminary evaluation stages and in situations requiring quick decision-making, the "Line Graph Comparison" method can also be used to score and perform a qualitative comparison (Belton & Stewart 2002).

In a study examining the most widely used methods within multi-criteria decision-making methods in the literature, the most commonly used methods were observed to be the "Technique for Order Preference by Similarity to Ideal Solution" (TOPSIS), "VlseKriterijumska Optimizacija I Kompromisno Resenje" (Multicriteria Optimization and Compromise Solution (VIKOR)), "Analytic Hierarchy Process" (AHP), and "Complex Proportional Assessment of Alternatives Under Grey Environment" (COPRAS-G) mathematical models (Beltrán & Martínez-Gómez, 2019; Bajwa et al., 2025). The "TOPSIS" method ranks alternatives by identifying the ones closest to and farthest from the ideal solution. It is an effective method for evaluating the performance data of physical and mechanical properties of building materials. "VIKOR" aims to find compromise solutions in multi-criteria decision-making problems. When evaluating alternative building materials, it aims to produce a solution that is closest to the best but also balanced and compromising in the decision-making process. AHP ensures the hierarchical structuring of criteria and sub-criteria in the decision-making process. This method is generally used in material selection to compare alternatives by weighting criteria. "COPRAS-G" is a method integrated with gray system theory, used to evaluate material alternatives in situations where data is unclear and there is uncertainty based on estimates (e.g., environmental impact, recycling potential, etc.).

3. Material Selection Criteria Evaluated within the Scope of Green Building Certification Systems

Green building certifications are systems used to measure and improve the environmental impact of buildings. They focus on criteria such as energy efficiency, water conservation, indoor air quality, material selection, and waste management in buildings. These certifications promote the sustainability of buildings, encourage their design and operation in an environmentally conscious manner, while also aiming to contribute to user health and reduce operational costs. Building Research Establishment Environmental Assessment Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) are widely used green building certifications worldwide. Green building certifications also provide various criteria for material selection.

The criteria outlined in these certifications are designed to reduce a building's environmental impact and enhance user comfort. In green building certification systems, the following criteria are emphasized: preferring materials with a high recycled content, locally sourced materials, and materials with a low carbon footprint; ensuring transparency through Environmental Product Declarations (EPD) for selected building materials; selecting products with low volatile organic compound (VOC) emissions for health and safety; products that do not pose a threat to user health and are free from toxic substances, and selecting building materials that are durable, easy to maintain and repair, and have a longer lifespan, thereby reducing resource use throughout the building's life cycle, are key considerations in building material selection (Deutsche Gesellschaft für Nachhaltiges Bauen, 2018; BREEAM, 2024; U.S. Green Building Council, 2025).

The LEED system evaluates material selection under the Materials and Resources (MR) category. This category accounts for 14 points out of the total 100 points in the LEED assessment. Materials used should be selected to minimize environmental impacts. In the Materials and Resources category, points are awarded based on the LCA impact, EPD sharing, health hazard status of material components, recycled content ratio, use of local materials, and use of materials produced from renewable sources (U.S. Green Building Council, 2025).

The DGNB system evaluates materials under the “Environmental Quality” heading. This category accounts for 40% of the evaluation. The Life Cycle Assessment (LCA) impact of building materials is important. It evaluates and scores the material's resource use, recyclability, waste generation, impact on indoor air quality, and durability (Deutsche Gesellschaft für Nachhaltiges Bauen, 2018).

In the BREEAM system, the Materials category evaluates the environmental impact and resource efficiency of material selection. The Materials category, examined in five sections, evaluates and scores the LCA impact, the sustainability of the material supply chain, sustainability certifications for materials (ISO 14001, etc.), the percentage of recycled or recyclable materials used, the durability of building materials, and their impact on human health. Table 1 provides the credit scores for the Materials section (BREEAM, 2024). The BREEAM certification scheme is customized for certain countries such as the UK and the Netherlands. For example, under the BREEAM-NL certification applied in the Netherlands, buildings can earn a total of 18 credit points for materials (BREEAM-NL, 2014).

Table 1. Credit Points for BREEAM Building Material Category (BREEAM, 2024)

Criteria	Credits
01. Building life cycle assessment	7 (+3 additional credit available)
02. Environmental product declarations	1
03. Responsible sourcing of building materials	4 (+1 additional credit available)
04. Durability and flexibility	1
05. Material efficiency	1

4. Haut Amsterdam Building

Haut Amsterdam, located in Amsterdam, the Netherlands, is a sustainable building designed by Team V Architecture. The project received an award in a project competition organized in 2016, where sustainability was of great importance in the evaluation phase. Every decision made during the design process of the building has been shaped by making choices in line with the principles of sustainability to serve the residential function, maximize the use of wood, and at the same time give the building the characteristics of a high-rise building. For this purpose, both functional and environmentally appropriate design decisions have been taken. The building, which was started in 2019 and completed in 2022, is the tallest wooden building in the Netherlands and the third tallest in Europe. The 21-story building is 73.00 m high. The total building area is 14,443 m² (Pintos, 2022).

Located on the banks of the Amstel River, the building prioritizes transparency of the façade, natural light and unobstructed views, and for this reason, a load-bearing wall system was applied inside, not on the façade, and these walls also function as dividing walls between the apartments (Fig. 1). This usage also made it possible to be flexible in terms of apartment size, plan layout and façade design (Vermeulen, 2022). Within the scope of the selection criteria of the building materials to be used in the building, sustainable, high quality and functional materials were targeted. For this reason, the use of wood, which will provide a significant carbon footprint reduction compared to the use of concrete or steel structural materials in a similar structure, was considered the most appropriate option, and its use was prioritized, aiming to minimize the embedded carbon footprint in the building (Verhaegh et al., 2020). In Dutch, haut means wood. It also allows for “Haute Architecture”, a name derived from the fashion term “Haute Couture”, allowing users to actively participate in the design of their apartments and decide on the size, number of floors, layout and balcony layout (Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6, Fig. 7), (Url-1, 2024).

Fig. 1. Haut Amsterdam Site Plan (Pintos, 2022).

To achieve a transparent appearance, provide natural heating through sunlight, and ensure optimal lighting, large glass facades with integrated solar panels have been designed. Solar panels have also been installed on the roof of the building. It is stated that 1,500 m² of solar panels are used on the facades and roofs (Pintos, 2022). Over 6,000 m² of corrosion-resistant anodized aluminum profiles have been used and anodized in the windows and doors of the building (Geberit TR, 2025). Additionally, the building includes sensor-controlled thermostats that detect and adjust heating and cooling, nesting boxes for birds and bats, and a rooftop garden for rainwater storage as part of its sustainability measures (Pintos, 2022). The building has achieved a BREEAM Outstanding rating with a score of 88.07% under the BREEAM-NL certification. The material score for the building is reported to be 83.33% (Fig. 8) (BREEAM-NL, 2023).

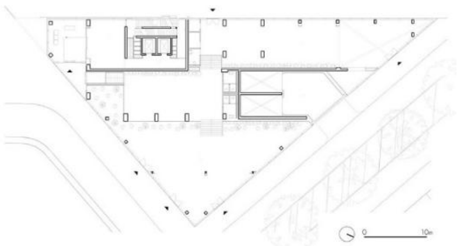

Fig. 2. Ground Floor Plan of Haut (Url-1, 2024).

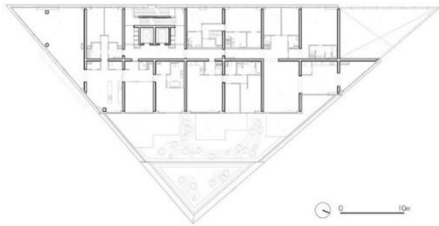

Fig. 3. 1st Floor Plan of Haut (Url-1, 2024).

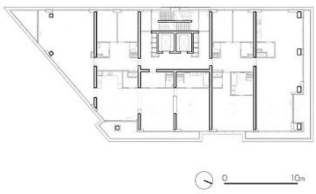

Fig. 4. 18th Floor Plan of Haut (Url-1, 2024).

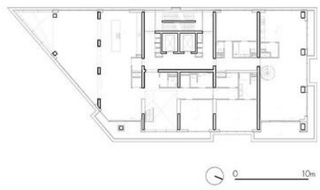

Fig. 5. 20th Floor Plan of Haut (Url-1, 2024).

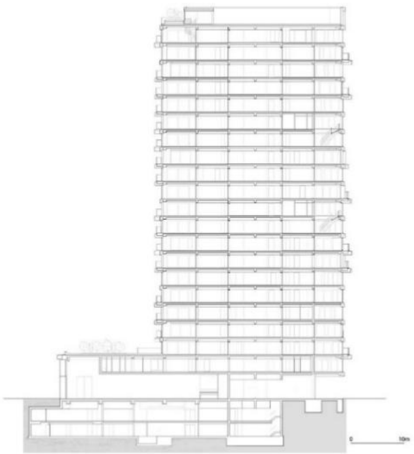

Fig. 6. Section of Haut .Amsterdam (Url-1, 2024).

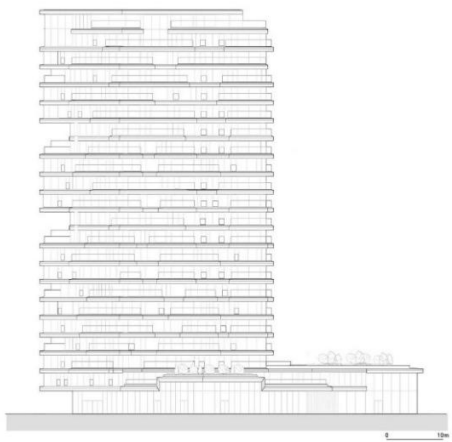

Fig. 7. East Facade of Haut Amsterdam (Url-1, 2024).

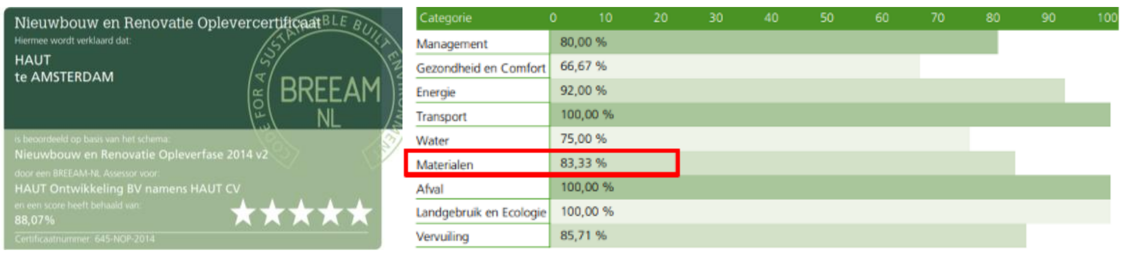

Fig. 8. BREEAM-NL 2023 Certificate for the Haut Amsterdam (BREEAM-NL, 2023).

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Due to Amsterdam's climate conditions, which are not suitable for the entire structure to be made of wood, the foundation, basement, and core sections of the building are constructed of concrete to provide resistance to wind and moisture, while the floors are made of Timber-Concrete Composite (TCC) and the walls are made of Cross-Laminated Timber (CLT) panels. Due to the limited space at the site and the lack of storage space, the wood-based materials such as TCC, CLT, and gululam used in the structure were pre-manufactured at a factory 200 km away and assembled at the site. The building uses 2,800 m³ of CLT, and the amount of wood used results in a 50% reduction in carbon emissions compared to other buildings, with approximately 1,800 tons of CO_2 stored. It is stated that the stored amount is equivalent to the annual CO_2 emissions of approximately 400 homes (Geberit TR, 2025).

Building Information Modeling (BIM) was used in the production process to ensure material supply, transportation, assembly, and all coordination. This enabled the entire production and building process to be planned, preventing issues such as limited space, storage, overproduction, waste generation, coordination, and communication deficiencies. It has been stated that project managers were able to view all production, planning, and building processes through BIM, enabling them to plan subsequent processes seamlessly. It has been noted that BIM provides advantages in project processes and significantly facilitates collaboration and coordination between various departments (Brüninghoff Group, 2022).

5. Examination of Sustainable Building Materials Used in the Haut Amsterdam Building

The building structure is designed to be sustainable, aiming for high quality and utilizing innovative building materials and components in material selection. Although the building's height, wide facades, and decision to use a significant amount of wood presented challenges, an integrated approach shaped the building design and production.The high material score of the building under the BREEAM-NL certification is believed to be due to factors such as the high amount of wood used in the building, the characteristics of the framing materials, the preference for solar panels in the facade and roof design, as well as the high LCA results, durability, and efficiency levels of these materials.

However, in this study, only anodized aluminum framing materials and wood-concrete composite panels were examined within the scope of sustainable building material analysis. This selection was made because these materials allow for a comprehensive evaluation in terms of both their functional and aesthetic roles in the building and the material selection criteria. Solar panels, on the other hand, were not analyzed within the framework of material selection criteria as they are considered a systemic energy production component.

The anodized aluminum framing material used in the structure are the AluBlack product from the Alumet brand. Anodizing is a transformative process that enhances aluminum's natural corrosion resistance and visual appeal through an electrochemical process. Anodized aluminum framing materials offer high solar reflectivity, ease of cleaning, the assumption that 100% of the material can be reused or recycled at the end of its life, a long service life, low carbon emissions, resistance to fire, corrosion, and scratching, and its sustainability. The product is certified to ISO 9001 QSC, ISO 14001 EMS, and Qualanod standards. (Fig. 9, Fig. 10), (Web2, 2024).

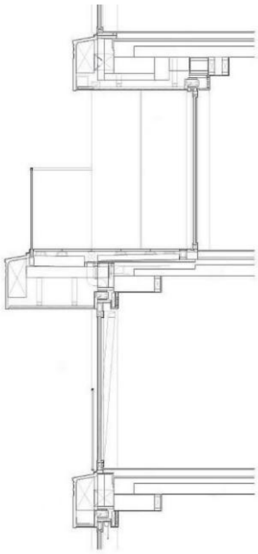


Fig. 9. System section (Url-3, 2024).

Fig. 10. Use of anodized aluminum framing material (Url-3, 2024).

The superior performance of Timber-Concrete Composite (TCC) in fire resistance and acoustic comfort compared to wood, its lower carbon footprint and higher carbon sequestration compared to concrete, its thinner and lighter weight enabling longer spans, and its modular design allowing for flexible design, and its superior performance compared to both wood and concrete under both compression and tension are the reasons why it is preferred for use in building.

TCC panel flooring used in building is obtained by combining two layers of 160 mm CLT panels and 80 mm C55/67 class concrete layers. In this system, where CLT and concrete are used together, CLT carries the tensile forces while concrete absorbs the compressive forces, thereby sharing the structural loads. TCC panel floors are prefabricated in a factory and assembled on-site. These panel floors are placed on top of CLT load-bearing walls (Verhaegh et al., 2020) (Fig. 9, Fig. 11). In areas where the floor edges are not supported by load-bearing walls, glulam (glued laminated timber) beams are used. The panel floors are installed so that the wooden surfaces are visible inside the building, ensuring an effective natural wood appearance in the structure (Brüninghoff Group, 2022; Frangi, 2022).

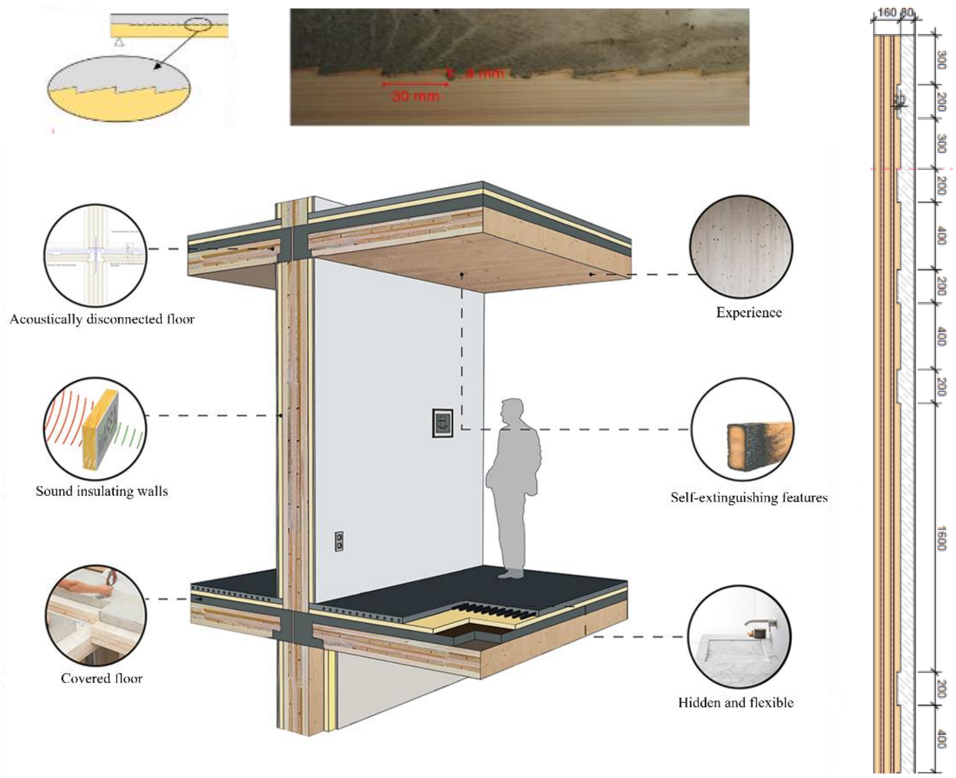


Fig. 11. Detail of TCC Flooring and CLT Wall Junction (Pintos, 2022; Brüninghoff Group, 2022; Frangi, 2022).

6. Evaluation of Building Materials Used in the Haut Amsterdam Building According to Building Material Selection Criteria

The Haut Amsterdam building scored 83.33% in the materials section of the BREEAM-NL certification. Buildings can earn a total of 18 credit points related to materials during the certification process (BREEAM-NL, 2014). Accordingly, the building earned 14.9 credit points. However, the certification system does not provide detailed information on which points were awarded.

The BREEAM-NL system evaluates the selection of building materials as follows:

- Assesses the environmental impact of materials used in the main components of the building.
- Examines whether materials are sourced from sustainable sources.
- Evaluates the lifespan and durability of materials used.
- Assesses the potential for reuse, modularity, and convertibility of the building and the materials used over time.
- Considers the recycled content ratio of materials and the use of reused building elements.
- Evaluates the amount, type, and management of waste generated.

Within the scope of the study, the anodized aluminum profiles and TCC panel flooring used in the Haut Amsterdam structure were examined in terms of sustainable building material selection criteria and evaluated by comparing them with the material score obtained by the structure under the green building certification. TCC panel flooring was compared with wood, reinforced concrete, and steel flooring, while anodized aluminum framing material was compared with aluminum, wood, and polyvinyl chloride (PVC) framing materials. Since a multi-criteria evaluation will be conducted for the assessment of building material selection methods, and weight values will be assigned equally, it was decided to use the Arıoğlu Method, Graphical Comparison Method, and TOPSIS method.

Similar to the BREEAM-NL certification system, the environmental impact, sustainability (CO_2 impact), fire resistance, sound insulation, durability, ease of application, flexibility in dimensions, recyclability, and environmental harmlessness of building materials will be evaluated. Therefore, the criteria to be compared for flooring are fire resistance, sound insulation, environmental and health safety, rigidity, weight (lightness), aesthetics, sustainability (CO_2 impact), ease of application (installation, production time), longevity/durability, and recyclability. The criteria to be compared for framing materials are fire resistance, sound insulation, environmental and health safety, weight (lightness), aesthetics, sustainability (CO_2 impact), ease of application (installation, production time), longevity/durability, and recyclability.

Within the scope of the Arıoğlu method:

- Criteria are determined.
- Each material is evaluated on a scale of 1-5 according to the defined criteria.
- The system with the highest total score is accepted as the most suitable solution. The value coefficient for each criterion will be taken as 1 (Kokulu, 2016).

Within the scope of the Multi Criteria Decision Making-Line Graph Comparison method;

- The criteria are listed on the horizontal axis.
- On the vertical axis, the scores each material receives for these criteria on a scale of 1 to 5 are marked.
- These scores are analyzed for each material, and a performance profile is created. (If a material's strengths are unbalanced, for example, very high in one criterion and very low in another, it is determined that the material is inconsistent. If a material's scores are balanced across all criteria, it is deemed to have balanced performance and is considered a suitable material).

Within the scope of the TOPSIS method;

- Alternatives are scored on a scale of 1-10 for each criterion (1 = very poor, 10 = very good).
- Criteria are normalized

$$\boldsymbol{r_{ij}} = \frac{\boldsymbol{x_{ij}}}{\sqrt{\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{x_{ij}^2}}}. \text{ (xij: alternatif i'nin kriter j için puanı)} \quad (1)$$

- The normalized matrix is multiplied by the criterion weights.

$$\boldsymbol{vij = wj \cdot rij} \text{ (Eşit ağırlıkta: tüm wj=0.1w\_j = 0.1wj=0.1)}$$

- The positive and negative ideal solutions are identified (P: the highest value in each criterion, N: the lowest value in each criterion).
- The distance from each alternative to the positive and negative ideal solutions is calculated.

$$\boldsymbol{s_i^+} = \sqrt{\sum_{\boldsymbol{j}} \left(\boldsymbol{v_{ij}} - \boldsymbol{v_j^+}\right)^2} \quad \boldsymbol{S_i^-} = \sqrt{\sum_{\boldsymbol{j}} \left(\boldsymbol{v_{ij}} - \boldsymbol{v_j^-}\right)^2}$$

(2)

- The proximity coefficient is calculated, and the resulting coefficient is taken as the TOPSIS score. The higher the score, the closer the solution is considered to the ideal solution (Chakraborty, 2022).

$$\boldsymbol{c_i} = \frac{\boldsymbol{S_i^-}}{\boldsymbol{S_i^+ + S_i^-}} \quad (3)$$

- After determining the criteria and scoring in the TOPSIS method, TOPSIS scores were calculated using TOPSIS software belonging to the "Decision Radar" web-based platform (Url-4, 2025).

Table 2 presents the evaluation of TCC, reinforced concrete, wood, and steel flooring systems according to the Arıoğlu method within the scope of the defined sustainability criteria. The flooring system material with the highest total score is "TCC" (Wood-Concrete Composite) flooring, which scored 44 points under the method. The maximum score that can be achieved under the method is 50. When the score of 44 is converted to a percentage, it results in 88%. The materials are ranked as follows: TCC first, followed by Timber, with Concrete and Steel sharing the same score.

A line graph of the flooring materials evaluated in Table 2 under the Line Graph Comparison method has been created in Table 3. According to this graph, TCC is the material with the most balanced line and the highest score. Wood stands out in terms of sustainability, aesthetics, and harmlessness, while it received low scores in fire resistance and rigidity. Reinforced concrete scored high in fire resistance and durability but low in harmlessness, aesthetics, and lightness. Steel is an effective material in terms of aesthetics and recyclability but scored low in fire resistance and sustainability.

The scoring on a scale of 1 to 10 for the flooring material selection criteria using the TOPSIS method is presented in Table 4. In the Decision Radar web-based platform, matrices were calculated by entering alternatives, criteria, and scores for each criterion for the TOPSIS score (Fig. 12). In the TOPSIS method, the most ideal selection is the option closest to 1; therefore, the most ideal flooring material option is TCC with a score of 0.80 (80%) (Table 5).

Table 2. Evaluation of Flooring Materials According to Sustainability Criterias Using The Arıoğlu Method.

Building Material	Fire Resistance	Sound Insulation	Harmlessness to Health/Environment	Rigidity	Lightness	Aesthetics	Sustainability	Ease of Application	Longevity / Durability	Recyclability	Total
TCC	4	4	5	5	3	5	5	4	5	4	44
Concrete	5	3	3	5	1	2	2	2	5	2	30
Timber	2	2	5	2	5	5	5	4	3	5	38
Steel	2	2	3	4	3	4	1	3	4	4	30

1: Not Appropriate, 2: Less Appropriate, 3: Moderately Appropriate, 4: Appropriate, 5: Very Appropriate

Table 3. Line Graph for Flooring Materials Evaluated Within The Scope of Sustainability Criterias.

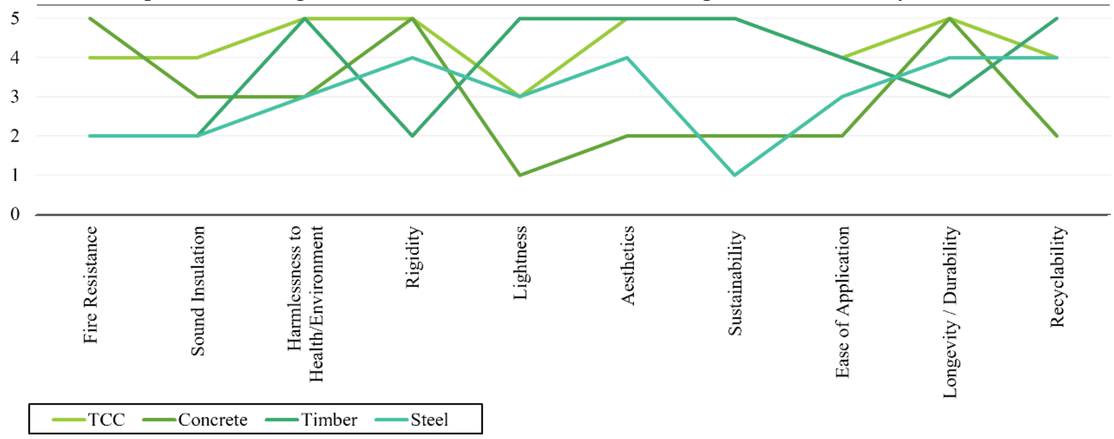


Table 4. Criterion Evaluation for the TOPSIS Score of Flooring Materials.

Criteria	TCC	Timber	Concrete	Steel
1. Fire Resistance	9	4	9	5
2. Sound Insulation	9	5	6	5
3. Harmlessness to Health/ Environment	9	10	5	6
4. Rigidity	9	5	10	8
5. Lightness	6	9	3	6
6. Aesthetics	10	10	4	6
7. Sustainability	9	10	4	3
8. Ease of Application	10	7	4	6
9. Longevity / Durability	9	7	10	8
10. Recyclability	9	10	5	8

Normalized decision matrix:

$$\begin{bmatrix} 0.13 & 0.14 & 0.12 & 0.11 & 0.09 & 0.13 & 0.13 & 0.14 & 0.10 & 0.11 \\ 0.06 & 0.08 & 0.13 & 0.06 & 0.14 & 0.13 & 0.14 & 0.10 & 0.08 & 0.12 \\ 0.13 & 0.09 & 0.06 & 0.12 & 0.05 & 0.05 & 0.06 & 0.06 & 0.12 & 0.06 \\ 0.07 & 0.08 & 0.08 & 0.10 & 0.09 & 0.08 & 0.04 & 0.08 & 0.09 & 0.10 \end{bmatrix}$$

Best answer vector: (0.13 0.14 0.14 0.12 0.14)
Choices distance from best vector: (0.03 0.08 0.14 0.12)
Worst answer vector: (0.05 0.04 0.06 0.06 0.05)
Choices distance from worst vector: (0.14 0.13 0.07 0.06)
Closeness vector of each choices: (0.80 0.61 0.37 0.32)

Fig.12. TOPSIS Score Matrices of Flooring Materials (Url-4, 2025).

Table 5. Calculated TOPSIS Score Result for Flooring Materials.

Flooring Type	TOPSIS Score	Sorting
TCC	0.80	1.
Timber	0.61	2.
Concrete	0.37	3.
Steel	0.32	4.

Table 6 presents the evaluation of anodized aluminum, wood, PVC, and aluminum framing materials based on the sustainability criteria defined within the Arıoğlu method. The framing material with the highest total score is anodized aluminum, which received 40 points under the method. The maximum score that can be obtained under the method is 45. When the score is converted to a percentage, it results in 88%. The material ranking is as follows: anodized aluminum, wood, aluminum, and PVC.

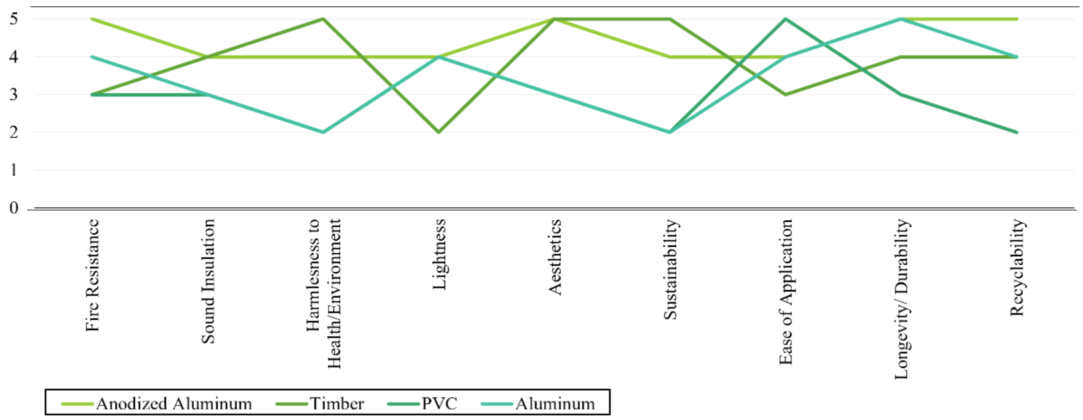
Within the scope of the Line Graph Comparison method, the framing materials evaluated in Table 6 have been plotted on a line graph in Table 7. According to this graph, anodized aluminum has the most balanced line compared to the other three materials, demonstrating very strong technical criteria (fire resistance, durability, recyclability) and moderate harmlessness. Wood is very strong in terms of environmental impact, health, and aesthetics but weak in terms of lightweight. PVC is high in terms of lightweight and ease of installation but receives low scores in terms of non-toxicity and service life. Aluminum is strong in terms of service life but receives low scores in terms of non-toxicity and sustainability.

Table 6. Evaluation of Framing Materials According to Sustainability Criterias Using The Arıoğlu Method.

Building Material	Fire Resistance	Sound Insulation	Harmlessness to Health/Environment	Lightness	Aesthetics	Sustainability	Ease of Application	Longevity / Durability	Recyclability	Total
Anodized Aluminum	5	4	4	4	5	4	4	5	5	40
Timber	3	4	5	2	5	5	3	4	4	35
PVC	3	3	2	4	3	2	5	3	2	27
Aluminum	4	3	2	4	3	2	4	5	4	31

1: Not Appropriate, 2: Less Appropriate, 3: Moderately Appropriate, 4: Appropriate, 5: Very Appropriate

Table 7. Line Graph for Framing Materials Evaluated Within The Scope of Sustainability Criterias.



The scoring criteria for framing material selection according to the Topsis method, ranging from 1 to 10, are presented in Table 8. In the Decision Radar system, matrices were calculated by entering the alternatives, criteria, and scores assigned to each criterion for the TOPSIS score (Fig. 13). In the TOPSIS method, the most ideal selection is the option closest to 1; therefore, the most ideal framing material option is anodized aluminum with a score of 0.72 (72%) (Table 9).

Table 8. Criterion Evaluation for the TOPSIS Score of Framing Materials.

Criteria	Anodized Aluminum	Timber	PVC	Aluminum
1. Fire Resistance	9	6	6	8
2. Sound Insulation	8	8	7	7
3. Harmlessness to Health/ Environment	8	10	5	6
4. Lightness	8	6	9	8
5. Aesthetics	10	10	7	7
6. Sustainability	8	10	6	6
7. Ease of Application	8	7	9	8
8. Longevity / Durability	10	7	6	9
9.Recyclability	10	8	5	8

Normalized decision matrix:
$$\begin{bmatrix} 0.09 & 0.08 & 0.08 & 0.08 & 0.07 & 0.07 & 0.07 & 0.09 & 0.09 \\ 0.06 & 0.08 & 0.10 & 0.08 & 0.06 & 0.09 & 0.06 & 0.06 & 0.07 \\ 0.06 & 0.07 & 0.05 & 0.07 & 0.07 & 0.06 & 0.08 & 0.05 & 0.04 \\ 0.08 & 0.07 & 0.06 & 0.07 & 0.07 & 0.06 & 0.07 & 0.08 & 0.07 \end{bmatrix}$$

Best answer vector: (0.09 0.08 0.10 0.08 0.07 0.09 0.08 0.09 0.09)
Choices distance from best vector: (0.03 0.05 0.09 0.06)
Worst answer vector: (0.06 0.07 0.05 0.07 0.06 0.06 0.06 0.05 0.04)
Choices distance from worst vector: (0.07 0.07 0.02 0.04)
Closeness vector of each choices: (0.72 0.59 0.17 0.43)

Fig. 13. TOPSIS Score Matrices of Framing Materials (Url-4, 2025).

Table 9. Calculated TOPSIS Score Result for Framing Materials.

Framing Type	TOPSIS Score	Sorting
Anodized Aluminum	0.72	1.
Timber	0.59	2.
Aluminum	0.43	3.
PVC	0.17	4.

7. Conclusions

The Haut Amsterdam building is a sustainable, environmentally friendly, and exemplary structure in terms of building material selection and building methods. The 83.33% score obtained in the building material usage section of the BREEAM-NL certification is a high score according to BREEAM standards. However, detailed information on each material could not be obtained.

The Timber-Concrete Composite and anodized aluminum materials were evaluated using the Line Graph Comparison, Arıoğlu, and TOPSIS methods, which enable the creation of evaluation criteria in accordance with the material section criteria of the BREEAM-NL Certification System and the subsequent evaluation of the multiple criteria using equal weight scores.

When evaluating flooring and framing materials used in the Haut Amsterdam building and their alternatives using the Line Graph Comparison method;

- TCC was found to be the most ideal among TCC, wood, concrete, and steel flooring materials.
- Anodized aluminum was found to be the most ideal among anodized aluminum, wood, PVC, and aluminum framing materials.
- The evaluation conducted within this method and the material selection made by the Haut Amsterdam building in line with its sustainability objectives were found to be compatible.

Under the Arıoğlu method, both TCC and anodized aluminum scored higher than other materials when compared. TCC scored 44 out of 50 points, while anodized aluminum scored 40 out of 45 points. When calculated as a percentage, both materials were found to be 88%. Under the multi-criteria decision-making method, the TOPSIS method was used to evaluate TCC and anodized aluminum profiles, and they were found to be the most ideal materials among the evaluated materials. The ideal ratio for TCC material is 80%, and the ratio for anodized aluminum material is 72%. Considering the lack of detailed information about all materials and the fact that the assessment was made on the basis of only two materials, the results obtained from the Line Graph Comparison method, the Arıoğlu method and the TOPSIS method were found to be consistent with the assessment of the BREEAM-NL certificate within the scope of the material criteria of the building.

In conclusion, it is considered that the Line Graph Comparison method can assist in selecting the ideal material within the scope of sustainable selection criteria, while the Arıoğlu and TOPSIS methods can help achieve results close to the evaluation and scoring methods of the BREEAM-NL certification within the scope of scoring methods.

Aknowledgement

This study was prepared within the scope of the Sustainable Building Materials course offered in the Fall Semester of the 2024-2025 Academic Year at the Department of Architecture, Graduate School, Gebze Technical University.

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The magical structural system of Munich Olympic Stadium

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Abstract. Munich Olympic Stadium is the main part of the Olympiapark Area since 1972, when the Summer Olympics took place. At that time, the structural solution of the canopy structure over the seats was really an extraordinary solution, not from architectural side but also from engineering side. Its architect, Günther Behnisch and its engineer, Frei Otto, designed a unique structure, still in service today, in 2025.The lightweight canopy structure is being carried by pilons, standing up at the back side of the seating area, all are at the different heights from the ground. Its transparent roof cover lets the structure be seen easily from everywhere.
The cables to support the cantilevered canopy structure go very far to be mounted to the ground level.
The experimental works of Otto, done before, prepared this special built product to get life.
Not only the Stadium is having a unique roof, but also all other closed spaces for different branches of the sport have special roof structures.
In the paper, it is aimed to underline the advantages of the canopy over the Stadium, constructed with structural steel and transparent cladding material, from the architectural point of view and also from the structural point of view, to call for the designs in future.

Keywords: Munich Olympic Stadium, Frei Otto, Günther Behnisch, Structural Steel, Pilons

1. Introduction

The Munich Olympic area, built in 1972, is still in service for the rescreation of the people. The transparent roof of the Stadium(Fig.1) has a very unique solution, not only in 1972, but also today(Aktuglu, and Orbay, 2024) (Aktuglu, 1999).

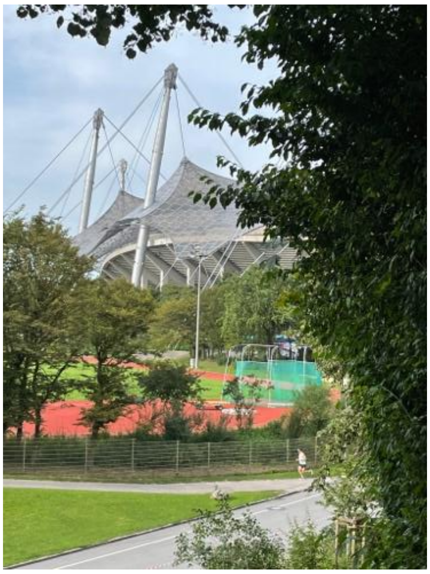

Fig. 1. The view of the Stadium from the road coming through SAP Garden (photo by B. Orbay and Y.K. Aktuglu, 09.08.2024)

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The structural solution of the seating area has its own elegant construction detailing also to let the total view of the stadium reflect the beauty of the whole structure in a very-well designed way to all. The outcomes of the partnership between architects and engineers should add the built environment a better case to attract others for the function through the Munich Olympic Stadium to Munich Olympic Area.

The design team of the roof of Munich Olympic Stadium is Behnisch and Partner, that Günter Behnisch, whose the famous works are the buildings in Munich Olympic Park (Gympel, 1996) and Frei Otto to solve the cantilevered roof, supported by cable net structures (URL-1, 2025). They have multiple saddle-shaped surfaces which are framed by edge cables. And they have suspended from masts. Pilons at the perimeter, support primary cables which in turn, they resist to interior network of interior cables and flying masts which gives the form of the structure of the roof. Roof area is 74.000m2. The width of cable net mesh i2 75*75cm. Edge cables are constructed by locked coil ropes. Guy cables are constructed by parallel strand bundles. Joints and connectors are made of cast iron. Masts/pilons are steel tubes in the form of puro. The first cover of the transparent roof was from acrylic glass which is Plexiglas. Then during the restoration of the roof in 1997, it has changed (Winney, 1998).

The innovative lightway structure of this roof solution, through imposing tensile structures for the Olympic Games here, (Fleming, 1991) also lets a whole section of the games watch with a clear view.

2. Details of the roof, call for magical structural system

The details of the roof and the stadium seating area and the connection of both of them, as seating places and roof over them, are enough good to understand the transfer of the loads from top to the ground(Fig.2.)(Fig.3.).

With the help of the novel large scale physical models, the design team could navigate to find the most suitable form for the transparent tent (Whitehead, 2022).

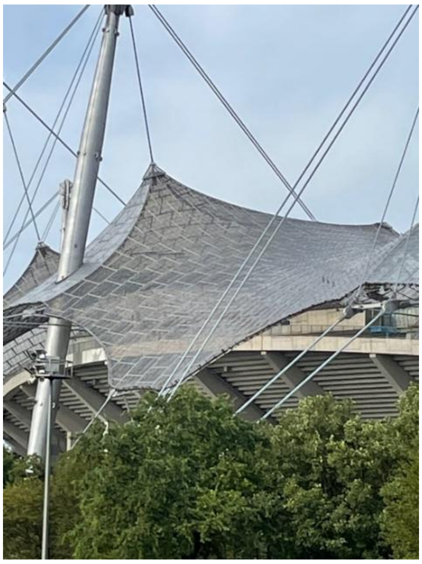

Fig. 2. The view of the whole structure with roof and the seating places (photo by B.Orbay and Y.K. Aktuglu, 09.08.2024)

Fig. 3. The view of the cables coming from masts and roof to the ground (photo by B.Orbay and Y.K. Aktuglu, 09.08.2024)

Fig. 4. The view of the end cables coming from the end of the cantilevered roof to the ground (photo by B.Orbay and Y.K. Aktuglu, 09.08.2024)

The end cables to stabilize the end of the cantilevered roof carried their loads to earth very strongly (Fig.4.). And double cables are used at the Munich Olympic Stadium (Blanc, 1993).

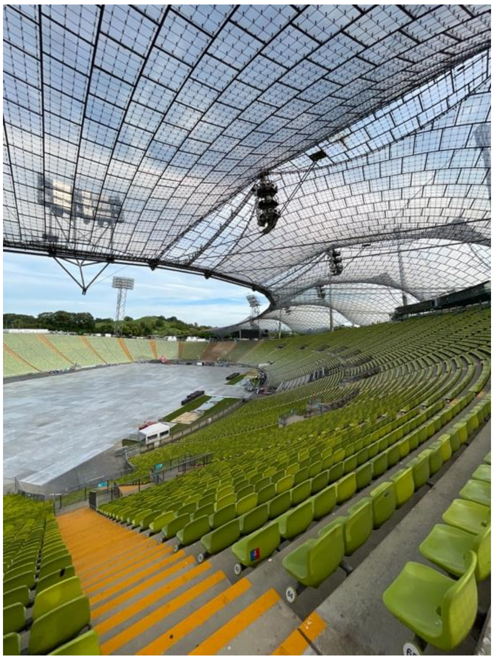

Fig. 5. The view of the transparent roof and the structure for the seating steps (photo by B.Orbay and Y.K. Aktuglu, 09.08.2024)

And the layout of seating places, together with the cantilevered transparent roof show how to have a clear view for the performances, eg sports, mucis performances, etc. which is the most important aim while designing the structure (Fig.5.).

4. Conclusions

As a conclusion, the whole structure of Munich Olympic Stadium and its cantilevered roof have lots of magical details to compose the roof and stadium itself. It is a very good case study to learn a lot about the complete cable net structure together with its steps under the roof for audience area (Fig.6.). The latest success of this landmark is that it is a very convenient structure and area for big music concerts eg. Coldplay had its concerts, on 13.08.2024, with lots of people.

What we may conclude that to have a real landmark structure as Munich Olympic Stadium, there should be a team with architects and engineers to solve the details, will stand more than 50 years, since 1972. The sustainability of this area and the cantilevered roof structure and the stadium comes automatically through its perfectly designed project, will lead to all of us, who will design the world through architecture and engineering of buildings and structures.

Multipurpose structures which are resilient, sustainable and with aesthetic properties is a stark reminder of how cities must work. An open area which can be used 365 days a year, suitable for any number of event types (even can used in natural disasters), which is also considered as a landmark is what every city needs to attract more attention. As its utilization rate grows, the structure’s lifetime value increases. Basically every city is better off with architecturally pleasing and functional structures, rather than just functional structures. The way Munich Olympic Stadium is a pristine example of enhancing cities with better design, better sustainability and better functionality. Even religious sites can be made more appealing and functional with such design and engineering.

Just for illustration purposes, such structures can be redesigned to go along with the local design patterns and serve as functional units. Regardless of the current need, below is an imaginary figure of a structure added as an extra attraction for Kayabaşı Yaylası in Akçaabat, Trabzon.

Fig. 6. A ChatGPT imagined implementation as an extra attraction for Kayabaşı Yaylası in Akçaabat, Trabzon.

Fig. 7. The whole view of the cantilevered roof and seats under the roof (photo by B.Orbay and Y.K. Aktuglu, 09.08.2024)

The main aim of this paper whose title as “The magical structural system of Munich Olympic Stadium” is to let architects and engineers remember to use cable net structures to span large meters without any obstacle in the space as a magical design, letting the roof fly in new stadiums, concert halls, airport buildings, and also residences, in not only urban area but also in everywhere of the world. For its form is very flexible, and also it is very light to construct, this cable net structure will add lots of advantage to the construction budget towards in a more positive way.

During the passing years, it will be very beneficial to visit this kind of unique landmarks from time to time, to investigate about what is changing in the structural details, due to the time.

Acknowledgments

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An evaluation of the use of energy performance simulations in Türkiye

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Abstract. The construction sector, which accounts for more than 40% of global energy consumption, shapes its significant share of energy consumption not only through production and implementation processes, but also through design decisions that have a direct impact on energy performance, from the choice of materials to the shape of the building. In this context, the use of energy simulation tools plays a crucial role in effectively managing energy efficiency during the design process and is becoming an indispensable tool for achieving sustainable design goals. Energy simulation programs (ESPs) not only enable designers to compare alternative solutions and make informed decisions, but also aim to optimize performance, reduce costs and ensure safety. The high energy consumption of buildings has necessitated the management of energy performance and led to the development of various software solutions in this area. Simulation programs make it possible to identify problems in the construction process at an early stage, facilitate the search for solutions and minimize errors. However, while energy simulations are frequently used in large-scale projects in Türkiye, in smaller projects energy and environmental factors are often only considered in order to fulfill legal requirements. Therefore, this study examines the reasons for the use of ESPs in Türkiye, identifies the types of programs used for different project sizes, and aims to increase planners' awareness of energy simulation tools. To analyze the use and preferences of ESPs in Türkiye, theses from the construction sector were selected as a sample. It was determined that EnergyPlus, DesignBuilder, Ecodesigner Star, Grasshopper, IES-VE, ANSYS Fluent and WUFI are globally recognized energy simulation programs. These programs were analyzed for their content and their capabilities were compared. Consequently, this study seeks to reveal the reasons behind the preference for ESPs in Türkiye.

Keywords: Architecture, energy, energy simulation, energy simulation programs (ESPs), graduate theses.

1. Introduction

The industrialization process has changed humanity's interaction with nature and has led to global environmental crises due to increased energy demand, emissions from production and rising consumption of natural resources in the 20th century. Unfortunately, with the expansion of industrialization and urbanization, the consumption of natural resources and raw materials has also increased, while studies on the efficient use of energy have remained insufficient and limited. This situation has not only exacerbated environmental problems, but has also significantly increased the demand for energy. Considering consumption figures, a large proportion of energy consumption is attributable to the construction sector. The construction industry directly influences energy consumption not only through its production processes, but also through its choice of materials and design decisions. The sector's high energy consumption has highlighted the need for sustainable design practices and energy efficiency-focused solutions. In this context, the construction industry plays a critical role in reducing environmental impacts and optimizing energy consumption (UNEP, 2019).

In the construction sector, various simulations can be carried out during the design phase to determine and optimize the energy performance of a building in areas such as heating, cooling and lighting. These simulations are crucial for improving energy efficiency in the early stages of the design process (Aziz N., et al., 2020). The energy performance of buildings is directly related to factors such as the choice of materials and systems, building form, and thermal insulation. Globally, the building sector accounts for around 40% of total energy consumption (IEA, 2020; Huang et al., 2018), with the operational energy consumption of buildings accounting for the largest share of this percentage. In response, many countries have set targets and developed regulations to improve the

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energy efficiency of buildings in order to reduce energy consumption and even construct near-zero energy buildings.

The life cycle of a building extends from the design phase through construction and operation to its eventual demolition. However, the environmental impact of a building is not limited to the construction phase. Over time, design errors can lead to significant environmental impacts during the operational period (Bueno et al., 2018; Hollberg & Ruth, 2016). Decisions made in the design phase play a crucial role in various environmental impacts, such as energy consumption, water management and waste disposal. At this point, design decisions made in the early stages are critical to the energy performance of a building. Considering that the average lifespan of a building is around 50 years (Kara & Kayılı, 2021; Hollberg & Ruth, 2016; Harputlugil, 2011), it is foreseeable that the environmental impact of poorly designed buildings will only increase over time. Therefore, the design phase is the most critical process for minimizing the environmental impact of a building. Since modifications or structural changes made later are often costly and inefficient, early detection of design errors provides significant environmental and economic benefits.

Building energy analysis and simulation programs calculate the energy consumption of a building by taking into account factors such as geographical location, the duration of sunlight exposure, the electrical appliances used in spaces, the number of occupants and their physical activities, and the materials used in construction (Kozan İ.H., 2021). In the design process, decisions such as the compatibility of a building with environmental conditions, the selection of materials and their application affect a larger scale, from the human scale to the national and global level. Regardless of scale, proper planning of performance requirements in design strategies is critical. These requirements can be effectively met through the integrated design of building subsystems (Hensen & Lamberts, 2011). The subsystems that influence building performance are shown in Fig. 1.

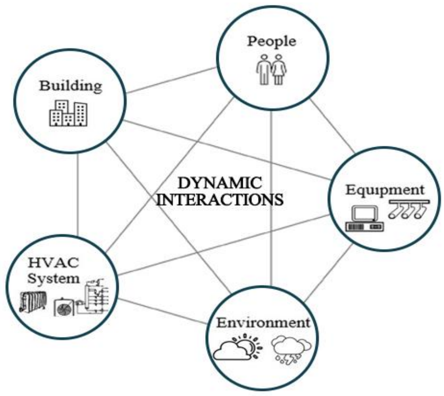

Fig. 1. Dynamic interactions of subsystems in buildings (adapted by authors from Hensen & Lamberts, 2011).

The complexity of building design requires the collaboration of experts from different disciplines to develop design solutions that meet all performance criteria (Yang & Bouchlaghem, 2010). However, dealing with conflicting interdisciplinary perspectives is a difficult, lengthy and complex process. Evaluating the energy performance of buildings and deciding on the materials and systems to be used requires complicated methods and interlinked calculations. In this regard, simulation programs that enable interdisciplinary collaboration, optimize energy consumption, maintain thermal comfort and reduce both short and long-term operating costs are essential. These programs, developed to model the energy consumption of buildings, help optimize energy performance during the design process and contribute to achieving the goals for zero-energy buildings (Hensen & Lamberts, 2011).

Energy simulation programs (ESP) were first developed in the 1960s to optimize energy consumption and, in particular, to reduce energy costs in large industrial and commercial buildings (Spitler, 2006). The lack of precision and practicality of manual calculations increased the demand for computerized analysis programs. Accordingly, building ESPs, which provide the ability to test expected performance criteria under different parameters, significantly reduce the workload of designers, facilitate effective decision-making in the design process and shorten this process (Kozan İ.H., 2021; Hensen & Lamberts, 2011; Yu Ş. et al., 2015). By using building ESPs throughout the design process, from the initial phase to completion, it is possible to calculate the heating and cooling energy demand, primary energy consumption of electricity and gas and energy efficiency criteria, as well as to determine the ideal range for thermal comfort for different time periods (Harputlugil & Hensen, 2006).

Today's building performance simulation tools, while diverse, generally operate based on real-time data and analytical calculations, are integrated with intelligent information systems, support fully integrated modeling, and provide interoperability with other software (Tunalı, 2012). The core theory behind these tools is based on the calculation of performance parameters such as heating, ventilation and air conditioning (HVAC) loads and the energy required. Numerous ESP software and tools have been developed by various companies and institutions. However, the selection of these programs varies according to their capabilities, advantages, disadvantages and limitations (Tunalı, 2012).

The aim of this study is to analyze the use and selection trends of these programs specifically in Türkiye and to identify the most commonly used ESPs. In addition, this study aims to evaluate the current status of energy performance simulation programs in the building design process, raise awareness among designers about the use of these programs and promote their integration into architects' workflows. In order to determine the input and output parameters of ESPs in the simulation process and to evaluate their frequency of use in Türkiye, a sample of graduate and postgraduate theses in the fields of architecture and civil engineering in the construction sector available at the YÖK Thesis Center until December 2024 were examined. Consequently, the study aims to identify the most suitable ESPs for Türkiye's conditions and needs in the field of energy efficiency and to provide a guide for future research on ESP selection.

2. Materials and Methods

This study focuses on determining the prevalence of energy performance simulations in Türkiye. The main objective is to identify the most commonly used energy simulation programs in Türkiye, examine their capabilities in data collection and analyze their advantages, disadvantages and limitations in comparison with each other. Within this framework, a search was conducted in the YÖK Thesis Center using the keyword "energy simulation" across all disciplines, admission status and thesis types. As a result of this search, a total of 158 theses were identified, including 128 master's theses and 30 dissertations.

Energy simulation programs are effectively used at various scales, from urban scale to buildings and building components. Accordingly, the data collected also analyzes how and at what levels these programs were used. The review identified which programs were used at each level. In order to ensure meaningful comparisons, the study was limited to simulation programs that were used in the construction sector and functioned at at least two different scales. Based on this criterion, the following energy simulation programs were analyzed: EnergyPlus, DesignBuilder, Ecodesigner Star, Grasshopper, IES-VE, ANSYS Fluent, MATLAB and WUFI. The research methodology and the methods used are summarized in Fig. 2.

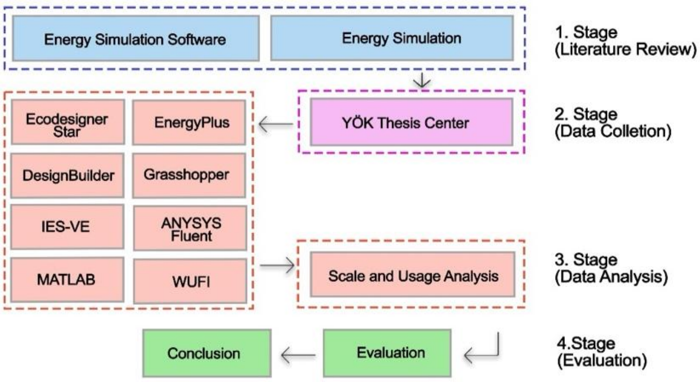

Fig. 2. Methodology Flow Diagram

3. The Use of ESPs in Türkiye

Energy simulation programs (ESPs), used to predict and analyze building performance in advance, have become significant tools that are much more effective and economical for eliminating potential problems before the use phase of buildings and increasing energy efficiency. They are constantly evolving to achieve accurate and appropriate modeling and performance calculations. In order to develop, evaluate, implement and standardize models and programs, global initiatives such as rating systems like LEED and BREEAM, incentive programs like the U.S. EPAct (Energy Policy Act) and regulations like the EPBD (Energy Performance of Buildings Directive) have been created (Hensen & Lamberts, 2011). In Türkiye, the construction sector has also issued the Regulation on the Energy Performance of Buildings (BEP), especially to optimize the energy efficiency of buildings and reduce the impact on the environment, and recommended the use of simulation tools, especially for large and complex buildings. The BEP regulation aims to define the calculation rules that allow an assessment of the total energy consumption in a building and to manage the energy consumption for heating, cooling, lighting and hot water production in buildings for primary energy (Harputlugil, 2014). However, most of these regulatory calculations are based on general assumptions and do not take into account the variable climatic conditions/regimes (Bayram, 2011).

The use of building performance simulations is generally limited to measuring the impact of façade designs on energy efficiency, estimating the risk of overheating in summer and heat losses in winter, and calculating the maximum cooling or heating load, taking into account equipment sizing (Augenbroe, 2002; Harputlugil, 2011; Hensen & Lamberts, 2011). ESPs are also used to optimize the use of natural daylight in buildings and/or to efficiently solve artificial lighting loads (Kalaycıoğlu & Yılmaz, 2019; Tozzi & Jo, 2017). All these simulations are used in a wide range, from urban scale to building scale and building component scale, to optimize energy performance (Hensen & Lamberts, 2011). In this context, it is crucial to accurately determine the scale on which energy consumption is calculated, paying attention to the targeted efficiency range. Accordingly, the first step is to decide on which scale the energy performance should be investigated and then select and use appropriate simulation programs that allow analysis on that scale.

The use of energy simulation programs at the building component scale focuses on analyzing the effects of the material properties and performance of the building elements on energy consumption (Harputlugil & Hensen, 2006). This scale focuses in particular on assessing the thermal transmittance of building materials, their thermal insulation capacity and their impact on energy efficiency, as well as measuring the impact of window and glass designs on thermal performance. It was found that DesignBuilder, EnergyPlus and MATLAB are the most widely used energy simulation programs that allow the processing of more specific material properties at the building component level. In addition, it was found that studies in the fields of architecture and civil engineering are more widespread at this scale than in other disciplines. Fig. 3 shows the energy simulation programs used at the building component scale and their disciplinary preferences, based on the analysis of the theses available in the YÖK Thesis Center.

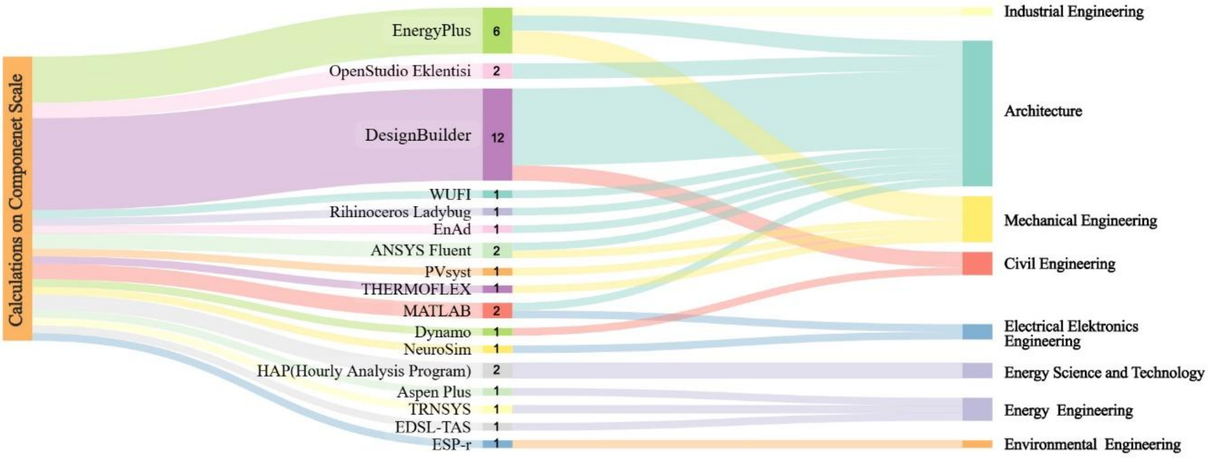

Fig. 3. Analysis of ESPs Used in Calculations at the Building Component Scale and the Studied Disciplines

As a result of the literature review conducted at the YÖK Thesis Center, it was found that among the 158 theses examined, analyzes were conducted at the building level in 124 theses, at the building component scale in 46 theses and at the urban scale in 27 theses. This finding shows that ESPs are not only used for specific calculations at a particular scale, but are also used in energy consumption analyzes at different scales. In support of this observation, 26 studies examined both building components and building scale together, while 13 studies considered both building and urban scales. The analysis results indicate that energy simulation programs in Türkiye are predominantly used at the building and building component level. Within this framework, the applications performed serve critical functions such as calculating heating and cooling loads, determining lighting and electricity consumption, evaluating indoor comfort and analyzing the impact of design decisions on energy efficiency (Hensen & Lamberts, 2011; Yu B. et al., 2015). Especially in the field of buildings, architecture is the area where energy simulation programs are most commonly used. The preferred energy simulation programs for calculations at the building level are DesignBuilder, EnergyPlus and eQuest.

In the field of architecture, these programs are generally used for applications such as the design of building envelopes, the analysis of the impact of building shapes on energy consumption and the evaluation of indoor thermal comfort (Kozan S., 2021). Energy simulations are also commonly used in the disciplines of mechanical and energy engineering. In these fields, energy simulation programs are preferred for the design of mechanical systems, the sizing of HVAC (heating, ventilation and air conditioning) systems and the optimization of energy systems (Aziz N.D. et al., 2020). However, in other disciplines, especially in fields such as electrical and electronic engineering and urban planning, the use of energy simulation programs seems to be quite limited (Fig. 4).

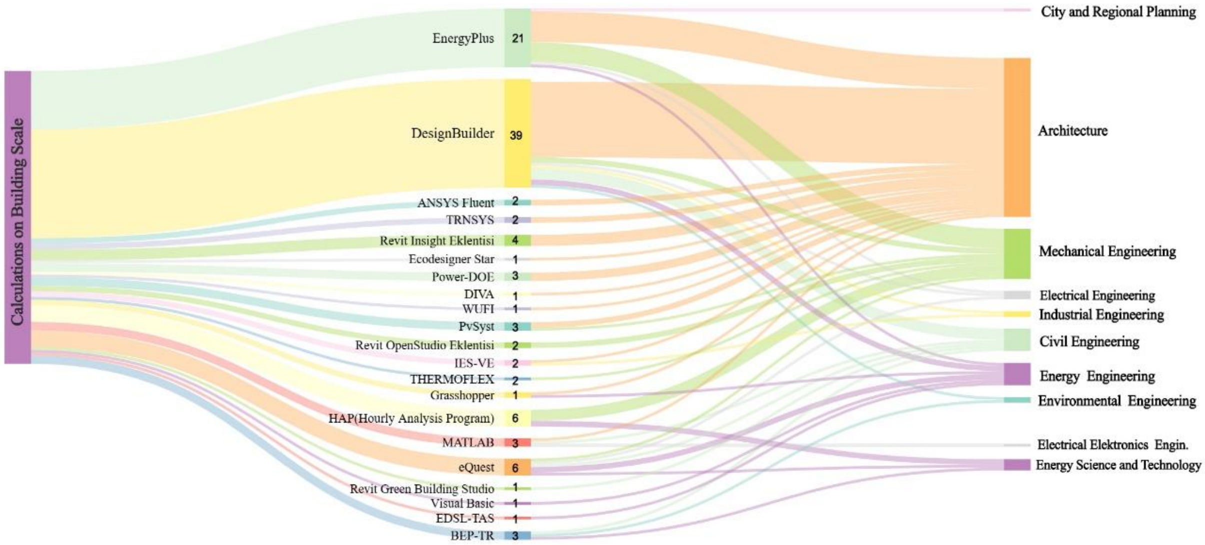

Fig. 4. Analysis of ESPs Used in Calculations at the Building Scale and the Studied Disciplines

It has been shown that the use of energy simulation programs at the urban scale is more limited compared to the building and building component scale. Urban-scale applications generally focus on specific topics such as solar radiation potential assessment, urban energy demand modeling, and energy system integration (Haung et al., 2018). At this scale, DesignBuilder, MATLAB and EnergyPlus are the most commonly used energy assessment software. Fig. 5 summarizes the energy simulation programs used at the city scale and the disciplines in which these programs are preferred. The overviews show that these calculations are primarily used to measure the interactions between buildings and to estimate their energy requirements. However, the limited number of studies in this area underlines the need for further development and widespread application of energy simulations at the urban scale.

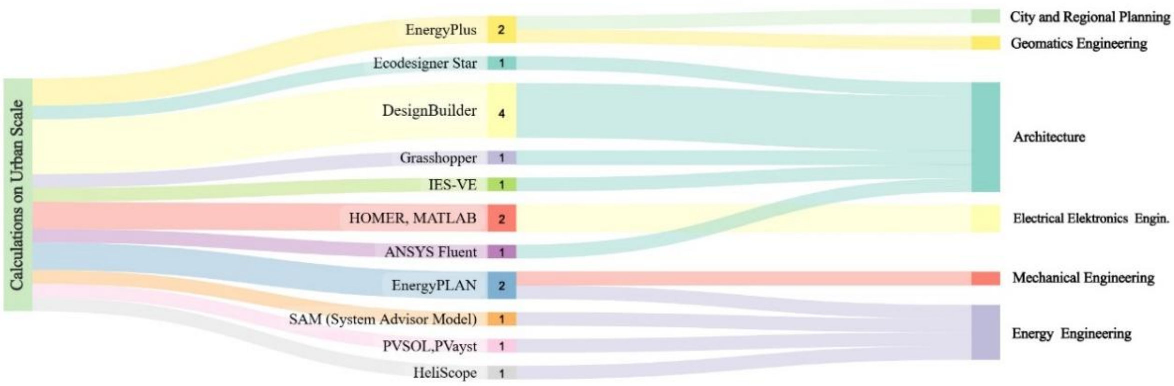

Fig. 5. Analysis of ESPs Used in Calculations at the Urban Scale and Studied Disciplines

Research has identified the most commonly used programs in all theses in Türkiye. The energy simulation programs used in the construction sector and suitable for different scales include Ecodesigner Star, EnergyPlus, DesignBuilder, Grasshopper, IES-VE, ANSYS Fluent, MATLAB and WUFI. In this context, these ESPs were examined individually in terms of the solutions they offer, the reasons for their preference and the specific problems they address.

3.1. EcoDesigner STAR

"EcoDesigner STAR was developed to enable highly efficient building design by converting Archicad Building Information Models (BIM) into multi-zone Building Energy Models (BEM). It enables the creation of thermal bridge analysis at any stage of the project within a short time and is used for energy efficiency analysis"

(EcoDesigner, 2024). The program offers advantages such as a user-friendly interface and integration with CAD programs, which makes it easier to use in practice. However, as more technical knowledge is required when working with complex models, it can be a disadvantage for new users (Yang & Bouchlaghem, 2010). In the studies examined, this software was preferred for performing simulations related to smart building design and energy consumption, as it allows the impact of green building applications and CO_2 emissions to be assessed.

3.2. EnergyPlus

EnergyPlus is an open-source building simulation software used to dynamically simulate heating, cooling, ventilation, lighting and other energy consumption systems in buildings while optimizing indoor comfort and calculating energy efficiency (Crawley et al., 2001). Due to its detailed modeling capabilities, it provides accurate simulation analysis for even the most complex systems. Additional features of this software include advanced window analysis, general building envelope calculations (external and internal surface convection algorithms), advanced infiltration and ventilation modeling, multi-zone airflow calculations, environmental emissions analysis, energy cost estimations and life cycle cost assessments (Saffari et al., 2017). However, since the input data is in text format, it is more difficult to use compared to programs with a graphical user interface (Tunalı, 2012; Tokuç, 2009). The reviewed theses indicate that this software is preferred especially due to its ability to create detailed models to simulate the interactions between the building and the external environment, to accurately model the potential of new integrated materials to optimize energy losses and to comprehensively calculate parameters such as energy consumption, indoor temperature, humidity and solar radiation gains.

3.3. DesignBuilder

DesignBuilder is a simulation engine that integrates EnergyPlus modeling and workflow control into a more user-friendly interface. It enables fast simulation of large models. DesignBuilder is a visual simulation program developed for the analysis of building energy consumption, carbon emissions, lighting and comfort controls (Aktacir et al., 2011). It is widely used to evaluate the impact of different design options on building energy consumption, perform life cycle analysis, assess façade options in terms of overheating and visual appearance, calculate the thermal performance of naturally ventilated buildings, predict daylighting performance through Radiance simulations, and determine the size of heating and cooling equipment (DesignBuilder, 2024). However, due to its limited ability for detailed modeling, it is not suitable for complex models. In studies conducted in Türkiye, it was preferred due to its ability to integrate multiple parameters into the model and develop a holistic approach to building design.

3.4. Grasshopper

Grasshopper is primarily a parametric design tool and is often integrated with Rhinoceros software. Integration with parametric modeling allows designers to quickly optimize the performance of buildings. This software mainly helps in testing and optimizing building components during the design process (Tunalı, 2012). However, it may be insufficient for performing highly detailed energy simulations. The studies reviewed show that Grasshopper has been used in simulations to analyze bioclimatic parameters for regional energy efficiency and to optimize the energy and daylighting performance of the building envelope..

3.5. Integrated Environmental Solutions Virtual Environment (IES-VE)

IES-VE enables detailed modeling of various parameters, including heating, cooling, electricity consumption and indoor comfort, enabling optimized building performance. It also provides comprehensive reports on the energy consumption and environmental impact of buildings (Hensen & Lamberts, 2011). IES-VE has a broad user base and is often used for energy simulations in the building sector. However, the user interface and functions can be very complex for new users. The software is primarily used to evaluate the effects of building shape on airflow and thermal conditions and to assess the performance of natural ventilation strategies.

3.6. ANSYS Fluent

ANSYS Fluent is a simulation program mainly used for computational fluid dynamics (CFD) and thermal analysis. It is typically used to analyze indoor airflow, thermal comfort and the performance of building components. In contrast to general building energy performance simulations, ANSYS Fluent is better suited for detailed component and system level analysis (Yang & Bouchlaghem, 2010). From the studies reviewed, it was mainly used to evaluate how the depth of courtyard design affects air movement, temperature distribution and indoor comfort.

3.7. MATLAB

MATLAB is often used for technical calculations and the development of algorithms. It enables customized calculations in simulations of the energy efficiency of buildings. However, the limited visual modeling capabilities and the required programming skills pose a challenge for new users (Harputlugil & Hensen, 2006). The studies examined show that MATLAB is primarily used for calculating solar radiation data and analyzing the performance of photovoltaic cells when assessing renewable energy consumption.

3.8. WUFI

WUFI is capable of accurately modeling moisture and heat transport in building components and provides detailed analysis in these areas (Künzel, 1995). However, its ability to evaluate the overall energy performance of buildings is limited and it often needs to be used in conjunction with other simulation programs for a comprehensive analysis. It has been widely used in studies to analyze the material properties of ecological thermal insulation materials, to evaluate dynamic thermal and moisture performance, and to assess airtightness.

4. Findings: Comparison of ESPs

As a result of the analyzes carried out of the areas of application and functions of energy simulation programs at different scales, a comparative table was drawn up to illustrate how these programs are used at urban, building and building component scales. In this context, the benefits of each program and their intensity of use were evaluated in detail. Table 1 summarizes these analyzes and shows the interdisciplinary usage trends of energy simulation programs.

Table 1. Advantages and Usage Intensity of the Analyzed Programs

Scale	**Usage**	**Ecodesigner Star**	**EnergyPlus**	**DesignBuilder**	**Grasshopper**	**IES-VE**	**ANYSYS Fluent**	**MATLAB**	**WUFI**	**TOTAL**
Urban Scale	Energy Demand Analysis	1	1	3	1	1	1	2	0	**10**
	Interaction Betwen Building	0	2	3	1	1	1	0	0	**8**
	Greenhouse Gas Emissions & Carbon Footprint Calculations	1	0	3	0	0	0	0	0	**4**
Building Scale	Heating and Cooling Systems	0	11	17	0	1	1	2	0	**32**
	Lighting and Elektricity Consumption	0	7	4	1	0	0	1	0	**13**
	Interior Comfort	0	7	4	0	1	2	0	0	**14**
	Efficiency for Construction	2	14	24	2	1	2	2	1	**48**
Component Scale	Insulation Materials	1	0	0	0	1	0	1	1	**4**
	Window and Glass Design	0	4	2	1	0	0	2	0	**9**
	Coatings and Structural Elements	1	5	9	1	1	2	1	2	**22**

The evaluations show that energy simulation programs are used extensively at different scales and for different purposes. The analysis shows that energy simulation programs are more limited at the urban scale compared to the building and component scale and are mainly used to assess energy demand. In particular, programs such as EnergyPlus and DesignBuilder are preferred for analyzing the interactions between buildings and energy demand processes. This indicates that these software tools are suitable for modeling energy performance on an urban scale. In addition, DesignBuilder stands out in the calculation of greenhouse gas emissions and carbon footprint, while other programs are not as commonly used for this purpose.

At the building scale, analysis of theses shows that the primary functions for which energy simulation programs are most commonly used are heating and cooling systems, lighting and electricity consumption, indoor comfort and structural efficiency analysis. In this context, EnergyPlus and DesignBuilder dominate across all application areas. In particular, DesignBuilder has a high usage rate for structural efficiency assessments. MATLAB contributes to specialized calculations, especially for indoor comfort and lighting analyzes. ANSYS Fluent is used less frequently than other programs, but plays an important role in the analysis of structural efficiency and indoor comfort.

At the component scale, the most important areas of application for energy simulation programs include thermal insulation layers, structural elements and the design of window openings. EnergyPlus is a powerful tool for simulating the heat transfer, material performance and energy impact of building components, making it particularly valuable for windows and thermal insulation layers. However, DesignBuilder remains the leading software for performance evaluation of building components and insulation methods. Due to its advanced capabilities in thermal and fluid flow analysis, ANSYS Fluent is used for detailed assessments of building components. MATLAB, on the other hand, enables the creation of detailed mathematical models and optimizations related to insulation materials, window design and thermal coatings and is characterized by its special functions. WUFI is primarily used to evaluate the performance of insulation materials, focusing on moisture and heat transfer, but has a more limited range of applications.

5. Evaluation and Conclusion

When analyzing how to improve the energy efficiency of buildings, energy simulation programs (ESPs) are proving to be effective tools for a holistic approach in which different alternatives are evaluated in the early stages of the planning process. ESPs are particularly important for optimizing the energy performance of large and complex multi-zone buildings as they provide realistic estimates (Harputlugil, 2014). In Türkiye, the Regulation on the Energy Performance of Buildings has created a framework that promotes performance analysis. This regulation emphasizes the need for the use of simulation programs capable of making detailed assessments at the urban, building and component scales. The research results show that in Türkiye, the use of energy simulation programs is more pronounced at the building and component scales, while the application at the urban scale remains quite limited. In addition, ESPs are used extensively in fields such as architecture, mechanical and energy engineering, while their use in other disciplines remains relatively low. This points to the need for a wider and more effective implementation of energy simulation tools at different scales and disciplines. Expanding their use will contribute significantly to achieving energy efficiency goals and promoting the development of sustainable buildings.

Table 1 in this study clearly summarizes the usage trends of ESPs in different disciplines and scales. At the building scale in particular, DesignBuilder and EnergyPlus are the preferred tools. However, strategies should be developed to increase the use of ESPs at urban and component scales. For example, raising awareness of programs such as WUFI and ANSYS Fluent, which are very effective in specific analyzes, could help to expand their user base.

In summary, the wider application of energy simulations across different disciplines is crucial to optimize the energy performance of buildings and contribute to global sustainability goals. The promotion of interdisciplinary collaboration and the development of more user-friendly software will support the more effective use of energy simulation tools.

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Algorithm-aided energy efficient building optimization

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Abstract. The depletion of energy resources has become a global issue, necessitating measures to reduce energy consumption. Since the construction process is one of the primary causes of energy consumption, methods to enhance energy efficiency from the design phase to the end of a building's lifecycle must be developed. This study adopts an energy-efficient approach to building design.

Simulation tools developed for energy performance assessment have not been widely adopted in the sector. The reasons include the continued use of traditional design methods and the perception that energy calculations add an extra burden to the design process. This study aims to develop a tool that provides designers with fast and effective alternatives. Accordingly, a parametric/algorithmic design and energy optimization approach was adopted, with a focus on residential buildings while considering zoning constraints.

The study employs swarm intelligence algorithms, specifically the Artificial Bee Colony to optimize energy performance calculations, which were implemented in MATLAB. A case study was conducted on an existing residential building, and the energy consumption of the existing structure was compared with the alternatives generated using the developed design tools. The results demonstrated that the new tool improved energy performance. This implies a 7.4% reduction in energy consumption, achieved through the optimization of architectural design parameters.

The proposed normative tool enhances energy efficiency in building design while promoting environmental sustainability. It can be adapted to different climatic conditions and building typologies and can be integrated with artificial intelligence to improve usability. Additionally, the system has the potential to be used by urban planners to guide zoning regulations and promote energy-efficient urban development.

Keywords: Energy efficient; Algorithm; Optimization; Early design phase.

1. Introduction

Architectural design has evolved into a complex, information-rich process influenced by environmental, legal, and technical data. Traditional intuition-based methods are no longer sufficient for addressing the increasing demands of sustainability and energy efficiency. With buildings accounting for approximately 37% of total energy consumption in Turkey (Canbay Türkyılmaz & Polatoğlu, 2012), the construction sector faces growing pressure to adopt more energy-conscious strategies starting from the early design phase.

This study focuses on the critical role of early-stage design decisions in shaping energy performance. It emphasizes that zoning regulations and building codes should not be treated as restrictions, but as parameters that can drive innovative and energy-efficient form generation. The research aims to develop an algorithm-driven computational tool that generates, evaluates, and optimizes multiple design alternatives within the boundaries of legal constraints. The tool uses criteria such as heating and cooling.

The proposed approach integrates energy simulation, generative design, and optimization into a unified framework. Instead of relying on separate plug-ins and manual data transfer between modeling and analysis platforms, the tool operates autonomously using swarm intelligence algorithms such as Artificial Bee Colony (ABC) (Karaboğa & Akay, 2007).

The originality of this tool lies in its in-house algorithmic foundation that performs design generation, performance analysis, and optimization in a single loop. It responds to limitations of existing CAD-based tools by offering a continuous workflow tailored for early-stage architectural design. By digitizing zoning constraints and embedding them into the generative logic, the tool ensures that proposed designs comply with regulatory frameworks while also achieving energy performance objective .

Overall, the study contributes to energy-efficient architecture by providing a holistic design methodology that integrates computational thinking with regulatory awareness. It offers architects and urban planners a scalable,

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adaptable solution to reduce environmental impact, increase design efficiency, and meet sustainability goals aligned with both national and international energy policies (OECD/IEA, 2017).

2. Material and Methods

This section presents the methodology used in developing an energy-efficient design optimization tool that integrates various parameters from environmental, regulatory, and building-related data sources. The aim is to improve architectural decision-making in the early design phase by incorporating energy performance considerations into algorithm-driven design generation. The data were categorized into three major groups: building data, legal regulatory data, environmental data. These inputs were digitized into matrices for integration into the algorithmic system. Regulatory data—including height limits, setback distances, and floor area ratios—were obtained from local zoning documents and similarly converted into numerical inputs to comply with computational requirements (Yasan,2011; Koengkan, 2023). Environmental data were collected from WhiteBox Technologies' climate files and from site-specific observations of topography, vegetation, and the spatial configuration of surrounding buildings. Building-related parameters were split into two categories: usage-dependent (occupancy levels, HVAC specifications, lighting and appliance loads) and design-dependent (form, orientation, WWR, envelope characteristics) (Morbitzer ,2001).Usage-dependent variables are typically undefined in early design and thus were assigned default values from literature (Gerçek&Durmuş Arsan, 2016). Design-dependent inputs, on the other hand, were dynamically generated through optimization algorithms, influencing building orientation, layout, and massin (He et al.,2020).

The methodology distinguishes between stable, dynamic, and area-dependent parameters. For instance, climate and topography are stable and fixed per location, while window-to-wall ratios and orientation are dynamic, adjusted per generated design iteration. This distinction allows the tool to maintain site-specific integrity while enabling design flexibility.

EPC simulation calculation data was used in the energy performance calculation of the existing building and for the design alternatives designed based on the algorithms.Energy performance assessment was based on EN ISO 13790 (2008), implemented through the Energy Performance Calculator (EPC) developed at Georgia Institute of Technology (Lee et al., 2013). EPC is a normative, monthly-based simulation tool widely accepted for evaluating annual energy consumption per unit area (EUI). It supports energy evaluations across heating, cooling, ventilation, hot water, and lighting systems by incorporating multiple international standards including EN ISO 13789, EN 15241–42, EN 15316, and EN 1519.

The EPC tool calculates total energy demand by balancing energy losses—via transmission and ventilation—and gains—via solar radiation and internal sources. EPC ensures that calculations reflect real-world conditions, aligning simulation accuracy with that of more complex dynamic tools (Lee et al., 201; Simmons,2011; Simmons et al.,2015; Zhang & Augenbroe,2018). Its outputs include monthly energy consumption, CO_2 emissions, and primary energy usage, providing a comprehensive dataset for optimizing sustainable building forms.

Optimization algorithm used in this study were Artificial Bee Colony (ABC) . Due to the infinite nature of design solution space, manual optimization is computationally infeasible. Therefore, swarm intelligence algorithms were employed to systematically explore design possibilities. These algorithms were implemented in MATLAB, which allowed seamless integration of EPC data through tabulated sheets for climate input, system configuration, and performance metrics (Uran & Jezernik,2016).

A seven-dimensional vector (short and long building edges, orientation, and the opaque-to-transparent surface ratios for each facade. Building height was excluded due to being pre-defined by zoning laws) was used to represent potential design solutions, allowing the algorithms to search within the bounds defined by setback distances, planned areas zoning regulation standards, and transparency ratios. The objective function and constraints were programmed into MATLAB using EPC-derived input data and structured to maintain realism and legal compliance. ABC algorithm was each run for 3,500 iterations, producing 70,000 design alternatives and enabling robust analysis of optimization efficiency.

Table 1. Representation of a Potential Solution – Design Parameters (Search space size)

Dim. 1	Dim. 2	Dim. 3	Dim. 4	Dim. 5	Dim. 6	Dim. 7
The short building edges	The long building edges	building orientation (main directions 0 intermediate directions 1)	opaquesurface /transparent surface	opaquesurface /transparent surface	opaquesurface /transparent surface	opaquesurface /transparent surface

In the field study section, the methodology described here was applied on an existing building.

2.1 Case Study
This section applies theoretical frameworks to real-world conditions by analyzing and optimizing the energy performance of a residential buildings in Konya, Turkey, through algorithmic design methods that integrate regional climate data and comply with regulatory constraints.

A parcel with a total area of 1425.88 m², located in Yaylapınar Neighborhood, Meram District, Konya Province, was selected as the project site (see Fig. 1). This building consists of 4 floors.The selection criteria included the presence of a low-rise building on the site and ease of access to zoning information.

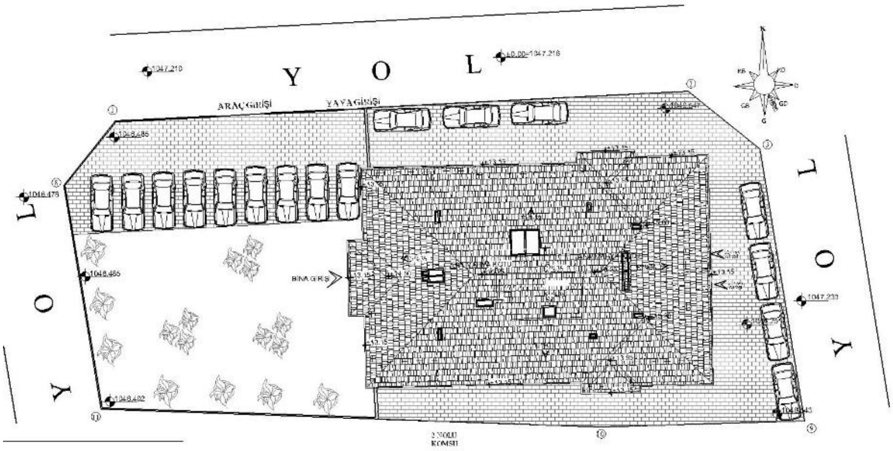

Fig. 1. Site plan of the existing building

Information regarding the existing land(zoning information) is as follows:

- Building Coverage Ratio (TAKS): 0.25 (can be increased by +0.05)
- Floor Area Ratio (FAR): 1.00
- Based on this, the calculated EPC data are as follows:
- Ground Floor Area: 1425.88 × 0.25 = 356.47 m² or 1425.88 × 0.30 = 427.76 m²
- Total Construction Area (FAR): 1425.88 × 1.00 = 1425.88 m²
- Volume: 1425.88 × 3.60 = 5133.16 m³ (Based on the maximum residential building height of 3.60 m according to Turkish Planning and Zoning Regulations)
- Setback Distance: Max. 18.90 m × 47.10 m

Information regarding the existing building data is as follows: EPC Data of the Existing Building:

- Ground Floor Area: 392.72 m²
- Total Floor Area (FAR): 1425.86 m²
- Volume: 5133.96 m³ (with h = 3.00 m)
- Transparent–Opaque Surface Areas: (see Fig. 2).
  - East: 130 m² (opaque), 85 m² (transparent)
  - North: 208 m² (opaque), 100 m² (transparent)
  - West: 140 m² (opaque), 75 m² (transparent)
  - South: 208 m² (opaque), 100 m² (transparent)
- Roof Area: 526 m²

Fig. 2. North,south,west east facades (form left to right)

The vectors of the existing building according to these criteria are given in Table 2.

Table 2. Early Design Parameters of the Existing Building

Dim. 1	Dim. 2	Dim. 3	Dim. 4	Dim. 5	Dim. 6	Dim. 7
17.00	24.36	0	140.05 / 75	208.15 / 100	130.05 / 85	208.15 / 100

Monthly energy consumption data of the existing building are given in Table 3.

Table 3. Monthly Energy Load of the Existing Building

Month	Monthly Energy Demand [kWh/m²]
January	25.13
February	26.85
March	21.7
April	16.53
May	19.65
June	23.48
July	27.19
August	26.74
September	21.92
October	17.24
November	23.96
December	29.05

Total: 279.43 kWh/m²

3. Result and Discussion

The findings of the field study are given in this section.

Information regarding the data of the Algorithmically Designed Building is as follows:. The building generated through algorithmic design must comply with the following criteria:

- Ground floor area must not exceed 427.76 m².
- Maximum short side length: 18.90 meters; long side length: 47.10 meters.
- Total site area must not exceed 1425.88 m².
- Roof area was calculated by adding 150 cm to both the short and long side lengths.

The vectors of the optimized building according to these criteria are given in Table 4.

Table 4. Optimized Design Parameters of the Algorithmically Generated Building

Dim. 1	Dim. 2	Dim. 3	Dim. 4	Dim. 5	Dim. 6	Dim. 7
18.83	18.91	0	45.19 / 180.76	45.38 / 181.53	45.19 / 180.76	45.38 / 181.53

Monthly energy consumption data of the optimized building are given in Table 5.

Table 5. Monthly Energy Load of the Optimized Building

Month	Monthly Energy Demand [kWh/m²]
January	23.07
February	25.55
March	20.93
April	15.28
May	18.03
June	21.27
July	24.53
August	24.15
September	19.93
October	16.15
November	23.07
December	26.84

Total: 258.79 kWh/m²

The comparison between the existing building and the algorithmically optimized one reveals that the differences in energy performance can be attributed to the following factors:

- Building Geometry

- Existing Building: Has a floor area of 392.72 m², a total FAR area of 1425.86 m², and a volume of 5133.96 m³. It is relatively taller and closer to a rectangular form.
- Optimized Building: Designed to remain within setback limits, it features a more compact and nearly square footprint. Reduced height and volume contribute to lower energy consumption.

- Surface Areas

- Existing Building: Has relatively larger total surface area and more transparent surfaces, which leads to increased heat losses and higher solar gain.
- Optimized Building: Surface areas are optimized for better thermal balance. Transparent areas are reduced, decreasing winter heat loss and summer overheating. However, a design limitation is the algorithm's tendency to converge toward the lowest transparency ratio regardless of orientation.

- Roof Area

- Existing Building: With a roof area of 526 m², it experiences greater heat loss since the roof is one of the primary surfaces for energy loss.
- Optimized Building: The optimized roof area, achieved by reducing side lengths, results in reduced thermal loss.

- Energy Consumption Results

- Existing Building: 279.43 kWh/m² annually
- Optimized Building: 258.79 kWh/m² annually

Table 6. The comparison between the existing building and the algorithmically optimized building

Building	Alternatives	Area	Short Side	Long Side	Taks	Kaks	Floor Number	Energy Consumption
Area	Border	1425,88	18,90	47,10	356,47	1425,88		
	Current		17,00	24,36	392,72	1425,86	4(h:12.65)	279,43
	Generated (ABC)		18,83	18,91	356,08	1424,30	4(h:12.00)	258,79
								20,64

According to the inference made from the data shown in Table 6; this implies a **7.4%** reduction in energy consumption, achieved through the optimization of architectural design parameters.

4. Conclusions

The global depletion of energy resources has made reducing energy consumption across all sectors an urgent priority. The construction industry, being one of the major consumers of energy, must adapt by implementing strategies that improve efficiency throughout a building's life cycle. This study responds to this need by adopting an energy-efficient approach during the design phase. The primary goal is to reduce energy consumption through a computational design method that integrates legal constraints and multiple design parameters.

Although various simulation and evaluation tools for energy performance exist, they are not widely adopted in the industry due to their complex data input requirements and the perception of energy efficiency as an additional burden. To address these challenges, this study developed a parametric design tool that facilitates rapid evaluation of multiple design alternatives, streamlining the workflow and helping designers incorporate zoning regulations, such as FAR and TAKS, into early-stage decisions.

After an extensive literature review, the Artificial Bee Colony (ABC) algorithm was selected for its effectiveness in solving architectural optimization problems. With the algorithm implemented in MATLAB and supported by EPC simulation data, a simplified energy optimization tool was developed. This tool was applied to residential building cases at different scales. Energy consumption for existing buildings was first calculated, and then compared with algorithmically optimized versions generated using ABC algorithm. Results revealed that optimized models exhibited better energy performance, achieving a noticeable reduction in energy consumption.

The tool also successfully incorporated zoning regulations and design constraints to produce practical, legally compliant and sustainable alternatives. It enabled fast and efficient generation of alternative layouts, demonstrating the potential to transform conventional design workflows. The tool's versatility allows for adaptation to different plot sizes, design typologies, and user-specific conditions, making it a scalable solution for sustainable architecture.

- This study presents a parametric design and optimization tool that integrates energy performance analysis with zoning regulations and environmental goals.

- The algorithmic design approach significantly reduced energy consumption through informed early-phase decisions.
- Swarm intelligence algorithm proved effective in generating diverse and sustainable alternatives under legal and design constraints.
- The tool provides a novel method for improving both energy performance and design efficiency in architecture.
- Future enhancements include AI-based personalization, adaptation to different climates and building types, and user-friendly interfaces for broader usability.
- The tool also offers potential use in urban planning by optimizing zoning parameters to prioritize sustainability at the city scale.

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Investigation of the effects of Wind-Driven Rain (WDR) on building facades: a case study of KTU kanuni campus

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Abstract. Defined as rain that moves horizontally in the atmosphere due to the effect of wind, wind-driven rain (WDR) has a greater potential to penetrate building facades compared to vertically falling rain. The increasingly heavy rainfall and strong winds due to climate change suggest that the rain driven by the wind will accumulate more moisture on building facades. This study aims to examine the effects of rain coming from different wind directions on building facades through photographs and to validate these effects using a moisture measurement device and a thermal camera. In this context, the study aims to determine the impact of wind-driven rain on building facades through photographs taken in the designated area, to detect the moisture accumulation on facade building materials using a moisture measurement device, and to make comparisons between the facades. As part of the study, the Kanuni Campus of Karadeniz Technical University in Trabzon, located in a temperate humid climate region, was chosen as the study area. Measurements were taken at the same points on a pilot building where visible deterioration of the building facades occurred due to atmospheric effects, using a humidity device, and meteorological data were recorded. Measurements were taken on the northwest facade, where winds can create intense rain and humidity effects on building facades when combined with humid and rainy climate conditions, the southeast facade, where winds can carry warm and humid air to the building facades and increase moisture damage on the materials, and the southwest facade, which is exposed to storms blowing from the west in every season. Based on the obtained measurement results, facade damages caused by moisture were compared according to wind directions, and the relationship between wind speed, direction, and precipitation intensity with the amount of moisture on the facade was analyzed. As a result, it was determined that the distribution of moisture varies in facades facing different wind directions. The highest humidity levels, contrary to expectations, were not recorded on the blank northwest facade facing the prevailing wind direction; instead, they were observed on the southwest facade, which is continuously exposed to western winds, where window frames are densely located, and the most damage was also observed.

Keywords: Wind driven rain (WDR); Climate change; Façade damages; Humidity measuring device; Masonry façade

1. Introduction

The 2023 report of the Intergovernmental Panel on Climate Change (IPCC) has revealed that climate change is leading to a wide variety of weather and climate extremes worldwide, and these effects are becoming increasingly evident (Intergovernmental Panel on Climate Change, 2023). Climate change is showing its effects in many areas, including the construction sector. In the construction sector, although studies on the thermal performance of building facades generally attract attention, rain and wind are also climatic elements that need to be considered and studied. As research continues on the changes in precipitation amounts, wind speeds, and primary wind directions as a result of climate change, one of the most significant impacts of these changes on buildings is the increasing rain and wind-related building damage.

Rain penetration means the entry of rainwater through window joints, walls, wall and window/door connections, wall joints, roof insulation, protrusions such as chimneys on the roof, and working joints. Water penetrating into the structure, even if not visible, causes various damages to the building (Özdeniz, 1978):

- Degradations in building materials and components,
- Decrease in thermal insulation capacity,
- Plaster blistering, decoration deterioration, staining,

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● Mold and moss on walls and ceilings,
● Separation of other cladding materials,
● Continuous freezing-thawing damage in systems made with lightweight concrete,
● The increased corrosion rate of the reinforcement and other steel supporting systems within the reinforced concrete.

Wind, while causing mechanical wear on building surfaces with the particles it moves, also creates pollution by accumulating elements like dust, smoke, and sand in the recessed and unprotected areas of facade surfaces. Additionally, the wind imparts a horizontal velocity component to raindrops that are expected to fall vertically, causing this water to strike the building surfaces. Rainwater striking the surface of the structure seeps in through cracks and openings due to its kinetic energy, causing both the wall to become wet and the existing damage to progress. This seepage triggers various physical and chemical degradation processes within the wall, causing building damage (Tüz, 1996).

Affected by the surrounding topology (natural and structural formations in the environment), building geometry (the height, shape, and surface structure of the building), facade details (facade materials, windows, balconies, etc.), and all relevant meteorological parameters, WDR can lead to various undesirable outcomes on the wall surfaces of buildings, such as mold formation, efflorescence, material degradation, freeze-thaw damage, water penetration, and surface pollution (Blocken & Carmeliet, 2004). As wind speed increases, raindrops move more horizontally, resulting in reduced protection from eaves and balconies that would otherwise shield against rain falling more vertically (Kubilay et al, 2016).

In the future, it is anticipated that the load of wind-driven rain (WDR) reaching the facades of buildings in a horizontal direction will increase due to the impact of more intense rainfall and wind events.WDR, which constitutes a significant environmental load for buildings, plays a decisive role, particularly on the hygrothermal performance and long-term durability of facades (Blocken & Carmeliet, 2004; Ge et al., 2017). The intensity and distribution of this load are significantly influenced by meteorological parameters such as wind speed, direction, and precipitation intensity, as well as geometric factors such as building configuration, geometry, facade details, and roof shape (Gholamalipour et al., 2024). Therefore, anticipating the impacts of climate change and designing building facades to withstand this increased load has become a critical necessity for sustainable building performance.

Studies on wind-driven rain (WDR) can generally be classified into two main groups: the first group focuses on research aimed at quantitatively determining the WDR load that buildings are exposed to (Blocken and Carmeliet 2004; Nik et al. 2015; Ge et al. 2017; Wang et al. 2020; Zhou et al. 2023); the second group examines the physical and performance-based responses of building facades to this rain load (Tang et al., 2004; Abuku et al. 2009) (Gholamalipour et al. 2022). This study, on the other hand, is a comprehensive and original research that combines both approaches by quantitatively determining the WDR load on facades facing different wind directions using moisture measurement devices and evaluating the responses of the facades to this load through thermal imaging and field observations.

Trabzon, which is the subject of this study, is located in the Eastern Black Sea region, is a coastal city, and exhibits a temperate humid climate with abundant rainfall almost every month of the year. In almost all the buildings located in the Eastern Black Sea Region, problems related to rain passage are encountered. In the facades of the buildings facing west and northwest, water and wind-related building damages have been observed (Özdeniz, 1978). The speed and direction of the wind, as well as the intensity of the rain, can cause different types of damage depending on the type of materials used on the building's facade, its design, and maintenance methods. As secondary issues resulting from building damage caused by moisture penetrating from the building facade, the deterioration of hygrothermal comfort, increased energy consumption, and higher maintenance and repair costs can be listed.

Considering the role of the building envelope in controlling climatic elements, it is vital during the design process to anticipate the varying environmental loads on different façades and to formulate tailored architectural responses. To design buildings that are resilient to changing climate conditions due to climate change and to prepare existing buildings for future climate conditions, it is essential to first understand the rain loads carried by the wind on building facades. For this purpose, in the study, the building damages caused by rain-driven water and moisture on the northwest, southeast, and southwest facades of the selected pilot building in the Trabzon KTÜ Kanuni Campus were examined and evaluated. Based on the evaluation results, design proposals for the improvement of the facades have been developed.

2. Materials and methods

Research on rainwater flow is conducted through field observations, field measurements, laboratory experiments, and both analytical and numerical modeling approaches. Field observations provide valuable qualitative data on the phenomenon. Findings from such observations indicate that rainwater flow typically initiates at the upper parts of façades where WDR (Wind-Driven Rain) intensity is highest, and that, in tall and wide buildings, the lower sections of façades are exposed to significantly less WDR due to the wind-blocking effect (Blocken et al., 2013).

It has been noted that most studies related to WDR have been conducted on isolated buildings. For a standalone building without specific façade details such as overhangs or balconies, the windward façade directly facing the prevailing wind direction receives the greatest amount of WDR. In the presence of a roof overhang, the maximum WDR occurs near the base of the windward wall, and this maximum value is considerably lower compared to that on a building without an overhang (Gholamalipour et al., 2022).

During precipitation events, prevailing wind directions cause significant exposure variations on different facade orientations of the same building (Kim et al., 2022). Wind speed and wind direction have a greater impact on the WDR on facades than rainfall intensity (Zhou et al., 2023).In line with this information, the study data have been supported by field measurements, not limited to just field observations. In this context, in the northwest, west, and southwest facades facing the directions where storms are most frequently observed, points close to the ground and at the corners were identified, and humidity measurements were taken in these areas on specific days. At the same time, meteorological data have been recorded simultaneously.

As the study area, the Kanuni Campus of Karadeniz Technical University, located in the province of Trabzon, where problems related to water ingress in building facades are observed due to its coastal location and heavy rainfall throughout the year, has been selected. The Biology Department building, located on this campus, has been considered the pilot structure (Fig. 1). Meteorological parameters (wind speed and direction) were obtained from the Trabzon Meteorology Station. As part of the study, during the preliminary fieldwork conducted on March 21, 2025, the facades and specific points for measurement were identified, field conditions were evaluated, and appropriate data collection strategies were developed. Additionally, trial measurements were conducted to verify the accuracy of the equipment. After this preparation process, humidity and temperature measurements were conducted at selected points on March 22 and April 26, 2025, to quantitatively determine the effects of wind-driven rain on the building facades. During this period, although the measurements were planned because the field conditions were suitable, according to the data from the Turkish State Meteorological Service, the months with the highest number of rainy days (an average of 13 rainy days per month) and relative humidity values in Trabzon are also March and April (Turkish State Meteorological Service, n.d.). Therefore, the study period provides an appropriate meteorological context for observing the WDR effect.

The Test building is a four-story building located in the KTÜ Kanuni Campus (Fig. 2). The Biology department, which started its education in the Mathematics Building in 1984, has been continuing its education and teaching in its building since 2000 (Karadeniz Technical University, n.d.). It has a slightly sloped roof without an eave. To the northeast, approximately 17 meters away from the building, there is a four-story building parallel to it. The building is 65 m long, with the northwest facade being 13 m wide, the southeast facade 20 m wide, and it is 13 m high. The building facades face the northwest, southwest, southeast, and northeast directions. Its short facades face northwest and southeast. It is quite open to the northwest (NW), west (W), and southwest (SW), which are the directions from which storms most often come, making it an ideal building for wind-driven rain studies.

Fig. 1. Study site (Karadeniz Technical University, n.d.)

Fig. 2. Test Building

2.1 Trabzon climate:
The region with a temperate humid climate; the coastal area facing the humid winds of the Black Sea and the high parts of the mountains receive abundant rainfall, while the valleys formed by the rivers cutting through the mountains and the southern slopes of the mountains receive little rainfall. In the rainfall regime observed in the coastal area, maximum rainfall occurs in autumn, while the amount of rainfall is at a minimum at the end of spring. In mid-August, heavy downpours moving from the northwest (NW) to the southeast (SE) are observed in the coastal region (Karadeniz, 1995).

In Engin's (2011) study evaluating 31 years (1960-1990) of observation data from the Trabzon Meteorology Regional Directorate, it was noted that in Trabzon, severe winds from the western sector were predominant in every season, followed by the northern sector. It has been determined that storms predominantly blow from the northwest (NW) (Karayel) direction, followed by the west (W) (Günbatısı) and southwest (SW) (Lodos) directions. When examined seasonally, it has been emphasized that storms from the western sector dominate in every season (Fig. 3).

According to Erinç (2014), the foehn wind movements occurring along the Eastern Black Sea coasts during the cold period blow as South (S) and Southeast (SE) winds.

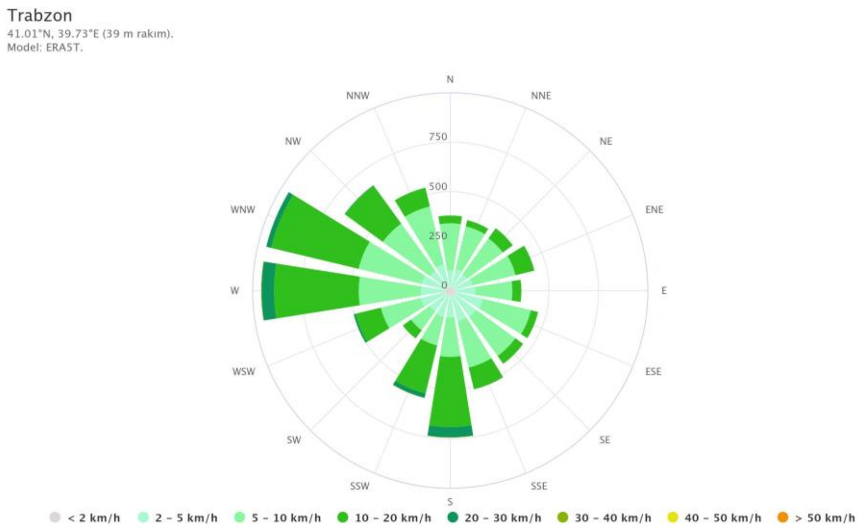


Fig. 3. Trabzon wind rose (Meteoblue, n.d.)

2.2 Moisture meter:
In order to support the field observations with field measurements, a portable Testo 606-2 moisture meter (measuring range from 0.7 to 8.6 %, measuring accuracy ± 1 %) was used to measure the facade moisture (Fig. 4).

Testo 606-2 (Testo, Lenzkirch, Germany) resistance moisture meter measures moisture-dependent electrical resistance using a pair of electrode nails driven into the structure.The device includes a sensor to determine the ambient temperature and relative humidity (Běťák et al. 2023).The feature of electrical resistance technology to reflect surface moisture distribution and provide a comprehensive regional assessment (Wang et al. 2024) has played a role in the selection of this moisture meter.

The field test was conducted on March 22, 2025, under overcast weather conditions with an average temperature of 8.6 °C. Then, about a month later, on April 26, 2025, another measurement was taken outdoors under an average temperature of 14.4 °C. The night before the measurements, the weather conditions were rainy. Measurement areas were determined on the northwest, southwest, and southeast facades of the test building. Since the southwest facade is the long facade, two separate measurement areas were determined in the north and south. A total of 4 measurement areas were obtained (Fig. 5). According to the studies in the literature (Abuku et al. 2009; Blocken et al., 2013; Gholamalipour et al. 2022), care was taken to place the measurement locations close to the wall edges and the ground, which receive the most WDR load after the facades. In each area, 5 moisture content readings were randomly taken, and the average moisture content of each area was calculated. Based on these calculations, the moisture content distribution was tabulated (Table 1).

2.3 Thermal imaging:
In addition to field observations and moisture value measurements, imaging was conducted on facades where moisture value readings were taken with a thermal camera to determine the hygrothermal performance of the structure. The thermal images taken with the Bosch GTC 400 C thermal imaging camera (Fig. 4), which provides rapid data sharing and easy documentation of thermal images, were measured while maintaining a fixed distance of 50 cm from the measurement point. The resolution is 160 × 120 pixels. Additionally, it has a thermal sensitivity of <50 mK, making even small temperature differences visible.Measurements range from -10 °C to +400 °C, with a measurement accuracy of ±3 °C.

Fig. 4. Testo 606-2 (Testo SE & Co. KGaA, n.d.), Bosch GTC 400 C (Bosch Professional, n.d.)

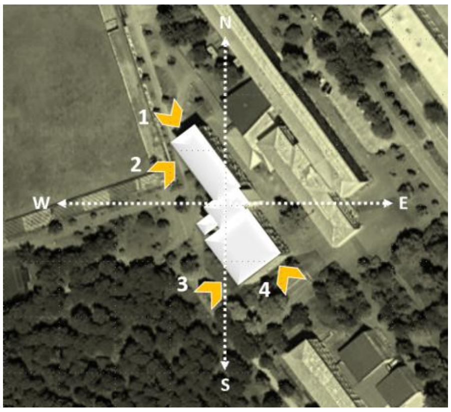


Fig. 5. Measurement points

3. Results and discussion
Fieldwork was conducted in two stages: field observations and field measurements, and the observations and measurements were examined by comparing them.

3.1 Field observations:
The northwest facade is a blank facade without openings such as windows and doors; although some paint spatter is observed, there is not much visible damage (Fig. 6). Paint and plaster applications are observed on the roof parapet edges and facade corners. Since a brick facade cladding of one and a half meters in height has been applied to the area close to the ground, there is not much damage caused by splashes and ground water, although some bricks have been found to have fallen in certain places.

The southwest facade is the facade where building damage is most commonly observed (Fig. 7).The edges of the facades, the edges and bottoms of the joinery are the areas where dirt and paint-plaster peeling are frequently observed.In buildings without eaves, the areas close to the ground on the wind-exposed facade are particularly where building damages are concentrated.

On the southeastern facade where the foehn winds blow, building damages are visible at the edges of the roof parapet, window sills, and the lower part of the enclosed balcony (Fig. 8).

Fig. 6. Northwest façade

Fig. 7. Southwest façade

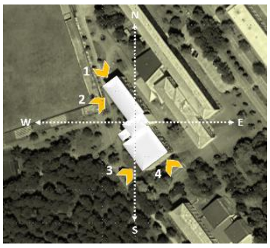
Fig. 8. Southeast facade

3.2. Field measurements:

In the study area, the average facade measurements taken with the Testo 606-2 material type hygrometer on March 22, 2025, and April 26, 2025, are presented in a table (Table 1). On Saturday, March 22, 2025, at noon, the weather, which had been rainy before, was very cloudy, with an air temperature of 8.6 °C, wind direction from the East, and an average wind speed of 4 km/h. On Saturday, April 26, 2025, at noon, the weather, which had been rainy in previous days, was clear, with a temperature of 14.4 °C, wind direction from the Northeast, and an average wind speed of 8 km/h. Looking at the humidity ranking, in the measurement on March 22, 2025, the highest humidity values were in the order of 3> 2> 1> 4 measurement points. In the measurement dated April 26, 2025, the highest moisture values are in the order of 2>3>4>1 measurement points.

In the study area, the images obtained using a thermal imaging device on March 22, 2025, and April 26, 2025, are presented in tabular form (Table 2). It has been observed that temperature differences occur on different facades. In the measurement dated March 22, the lowest temperature at the measurement point 1 located on the northwest facade was measured as 11.5 °C, while the area close to the brick-covered ground was measured as 12.9 °C.In the images taken from two different measurement points on the southwest facade, the measurement point number 2, where the humidity value in the wall under the window was lower, showed a higher temperature compared to the measurement point number 3. In the measurements taken on April 26, while the humidity levels on the facades generally decreased, the temperatures on the wall surfaces increased due to the rise in air temperature.At measurement point 1, the highest temperature was measured at 16.8 °C, while the area near the brick-covered ground was measured at 14.8 °C. In the images taken from two different measurement points on the southwest facade, the highest temperature measured at the second measurement point, where the humidity value is higher on the walls under the window, was lower than the highest temperature measured at the third measurement point. At measurement point 4, the lowest temperature was measured at 17.3 °C and the highest temperature at 20.2 °C.

Table 1. Measurement results



Measurement point	Facade direction	Average humidity value (%)	
		22.03.2025	26.04.2025
1	NW	1.4	0.8
2	SW	2.4	1.2
3	SW	2.6	1.1
4	SE	0.9	1.1

Table 2. Thermal images

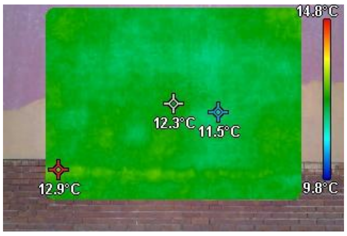
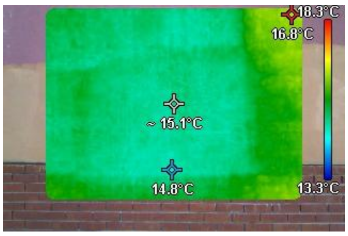
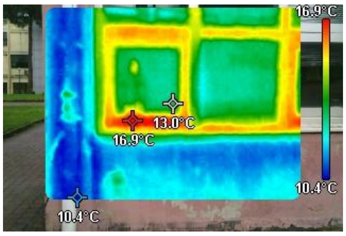
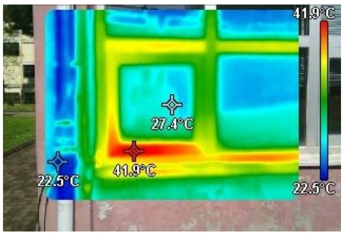
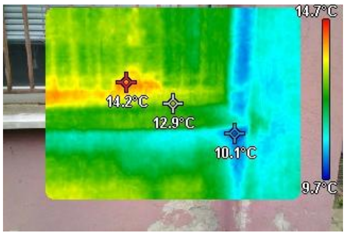
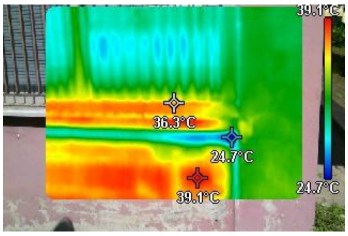
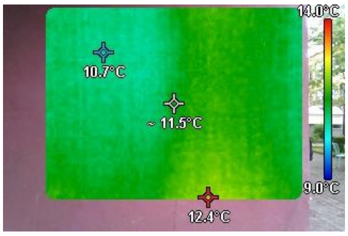
	Measurement point	Facade direction	Lowest temperature (°C)	Highest temperature (°C)	Thermal image	Real image
22 March 2025	1	NW	11.5	12.9		
26 April 2025	1	NW	14.8	16.8		

Table 2 continued

22 March 2025	**2**	**SW**	**10.4**	**16.9**		
26 April 2025	2	SW	22.5	41.9		
22 March 2025	3	SW	10.1	14.2		
26 April 2025	3	SW	24.7	39.1		
22 March 2025	4	SE	10.7	12.4		
26 April 2025	4	SE	17.3	20.2		

3.3. Discussion

When the field observations and humidity measurement results are evaluated together, it has been observed that both data sets are generally consistent with each other; however, there are differences in some facades. As predicted, it was observed that the distribution of humidity also varied on facades facing different wind directions as a result of the measurements taken.

Firstly, when examining the difference between the experimental measurement conducted on March 21, 2025, and the measurement on March 22, 2025, it was observed that due to the measurement taken after prolonged rainfall on March 22, there was a significant increase in humidity levels on all facades. The significant increase in humidity levels on March 22, 2025, compared to March 21, indicates that the rainy weather conditions from the previous night directly affected the moisture accumulation on the facade surfaces. This situation has been significant in relating the obtained humidity values to environmental conditions. In the measurement dated April

26, it was observed that the humidity values measured on the facades had significantly decreased. It is believed that this situation was caused by the air temperature rising to approximately twice that of the previous measurement days. Nevertheless, the southwest front is still the one with the highest humidity value.

According to Tang (2004), building walls facing the prevailing wind directions generally receive more driven rain, but understanding the distribution of rain due to local airflows and the wind's influence is challenging due to limited data sets and complex interactions. As visually analyzed in the field observation, it was determined that the facade with the highest moisture content is not the blank NW northwest facade, which receives the most wind, but rather the SW southwest facade, which is continuously exposed to west winds due to the opening in front of it and has many window frames and thus joints. In this case, it is believed that local airflows and local winds, as well as other parameters (environmental factors, building geometry, surface characteristics, etc.), are also influential.

Especially on the southwest facade, the intense deterioration observed during field inspections (paint peeling, plaster spalling, pollution, and material delamination) overlaps with the high humidity levels determined in field measurements. This situation confirms that the inadequacy of the structural joint details and direct exposure to wind increase moisture accumulation. Despite the presence of sills on the windows of the southwest facade, the extensive damage is believed to be caused by the impact of rain droplets driven by the rapidly arriving wind and errors in the joinery-sill-building connection details. The inadequacy of solutions to ensure waterproofing at the junctions of the sill and wall, as well as the absence of drip edges, may have contributed to this situation. However, it is estimated that the water coming from the ground through splash and capillary action has caused damage to the wall above the ground. It is thought that the change in the percentage ranking of moisture values in two measurements at two points (measurement points 2 and 3) on the SW facade, where the most facade damage is observed, may be related to the instantaneous variation in wind direction.

Observations for the northwest facade have revealed that there is limited surface deterioration, particularly with localized peeling in the brick cladding areas. In the measurement results, lower moisture values than expected were obtained on this facade compared to the other facades. This situation suggests that the lower moisture levels can be attributed to the façade being a blank wall, lacking joints or connection points (such as window frame-wall intersections) through which rainwater could penetrate the inner layers.

The southeastern front stands out as the least affected front in terms of both field observations and measurement data. The limited visual distortions observed are consistent with the low humidity levels in the measurement results. In the first measurement at the 4th measurement point on the SE facade, the lowest humidity value was observed, which is thought to be due to the presence of a closed balcony on the facade and the wall and trees in front of the measurement area reducing the impact of rain driven by the wind. In the second measurement, it is thought that the reason the average humidity value on the SE facade was not the lowest, despite the increasing temperature, is due to the trees in front of the facade and the covered protrusion on the facade casting shadows on the measurement point. It is thought that the projections, trees, and neighboring structures on this facade are physical barriers that restrict the rain carried by the wind from directly reaching the facade.

As a result of comparing thermal camera images with humidity measurement data, a direct and reciprocal interaction between the amount of moisture on the building facade and the surface temperature has been identified. It has been observed that damp surfaces generally exhibit lower temperature values. It is understood that this situation leads to lower temperatures in the relevant areas compared to their surroundings as a result of the evaporation process occurring on the surface and the heat being removed from the environment. However, as predicted, it has been determined that in areas where building damages are visible and at the window-wall junctions, the temperature values are either lower or higher, resulting in heat losses. In the blank facades (northwest and southeast directions) where building damages are less observed, it has been determined that the differences between the lowest and highest temperature values are more limited. This finding reveals the relationship between building damage and the moisture balance and thermal comfort conditions of the wall surface, demonstrating that the moisture effect directly influences surface temperature fluctuations. It is anticipated that moisture accumulation can adversely affect the indoor temperature and humidity balance of the structure, which in turn may lead to a deterioration of indoor comfort conditions and an increase in energy consumption for heating.

The comparison made reveals that not only the visual distortions observable on the facade surface, but also the moisture accumulating beneath the surface, play a significant role in the formation of building damages. When limited to visual observations, it may not be possible to detect internal deterioration caused by moisture sources that structural elements are exposed to, indicating that field inspections must be supported by technical measurements. Quantitative analysis methods such as moisture measurements and thermal imaging reveal subsurface moisture movements and the potential damage they cause, allowing for a holistic assessment of structural health. Therefore, to accurately analyze the performance of the structure and effectively determine intervention strategies, it is critical to not only rely on observations but also to complement them with scientific measurements.

4. Conclusions

In this study, the effects of wind-driven rain (WDR) on building facades have been examined through both visual field observations and quantitative field measurements.Based on the findings obtained, the following conclusions have been reached:

- On the Northwest facade, which faces the Northwest where storms are most commonly observed, no expected high humidity levels or significant damage were observed due to the absence of openings and joints. However, some paint-plaster peeling and brick falls were observed on the brick facade cladding and the roof parapet edges.
- At the southwest facade, it has been observed that rain droplets, driven by rapidly coming winds, are causing severe facade damage due to structural joint errors and lack of waterproofing.
- Due to the effects of the foehn winds, structural damage has been observed on the edges of roof parapets, window sills, and under enclosed projections on the southeastern facade; however, the low humidity at the measurement point, the enclosed projection, and surrounding obstacles have reduced the wind's impact.
- As a result of the measurements taken, it was observed that the distribution of moisture varied on facades facing different wind directions. The facade where the most moisture was observed was not the blank northwest facade where the prevailing wind comes from, but the southwest facade, which is constantly exposed to western winds and has many window frames, and where the most damage was also observed.
- An increase in humidity levels has been observed after prolonged rainfall. With the increase in temperatures, a decrease in humidity levels has been observed.
- The ranking of humidity values at the measurement points varies due to instantaneous changes in wind direction and the influence of environmental factors.

Considering the changing climate conditions and increasing humidity levels, design solutions that can bear the moisture load should be developed and implemented in the facades of newly constructed buildings to ensure cost and comfort efficiency. Improvements should be made in existing buildings. In existing or newly constructed buildings, the following recommendations are made to consider wind-driven rain loads and prevent their adverse effects:

- Different design solutions can be applied according to the directions.
- Problems can be prevented with appropriate detailing on facades (steel angle brackets, joint sealant, polyethylene foam filling, etc.) (Swinton & Kesik, 2005).
- Even a small facade detail (e.g., a 10 cm window sill) can reduce the WDR load by up to 37% (Kubilay et al., 2016).

In conclusion, measures such as selecting the right materials, waterproofing, and calculating wind loads are necessary to enhance the durability of building envelopes against wind-driven rain. Reducing the impacts of such environmental factors, extending the lifespan of buildings, and increasing energy efficiency are very important in terms of lowering economic and environmental costs.

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Capillary active thermal insulation materials used in architecture

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Abstract. Approximately 40% of the energy produced worldwide is used in the construction sector. 60% to 80% of the heating and cooling loads in buildings are due to heat transfer through the building envelope. Among these building elements, external walls play a major role and can account for approximately 25-30% of the total heat loss. Studies on enhancing the energy efficiency of historic buildings are crucial because 30% of the current building stock is classified as historic. It is unable to insulate buildings with cultural historical value from the outside due to the preservation of their original architectural expression. Today, it has been suggested to use capillary active insulation materials as substitutes for traditional insulation materials. Those materials with their specific hygrothermal characteristics, have also been determined to enhance building energy efficiency. Capillary active thermal insulation materials allow the moisture that may accumulate at the interface between wall structure and thermal insulation resulting from the rain water pushed from the outer surface of the facade and/or condensation of the vapour transmitted from the inside to the outside to dry inwards. Hence in this study, recent research done on capillary active thermal insulation materials; their practical applications in architecture and comparative material properties according to the expected performance requirements are scrutinized and probable potential materials that can be used for this aim are suggested by literature review. With the recommended capillary active insulation materials given in this study; in cases where it is necessary to preserve the character of the building facade, the energy cost can be reduced by reducing the heat loss of the building and a healthy indoor environment free of mold and moisture will be created.

Keywords: Interior insulation; Hygrothermal performance; Capillary active insulation; Capillary absorption coefficient; Thermal conductivity

1. Introduction

As the targets for reducing energy consumption increase in the world, it has become important to take energy improvement measures in existing buildings. For this purpose, it is planned to introduce minimum energy performance standards, to gradually remove buildings with poor performance from use, to continuously improve the building stock and to achieve the target of a decarbonized building stock by 2050 (Energy Performance of Buildings Directive, nd). Buildings account for 40% of energy consumption (Directive - 2010/31 - EN). More than 60% of residential buildings were built before 1960 (Hansen et al., 2018).

One of the natural precautions taken in the building envelope to reduce energy consumption is thermal insulation. Thermal insulation is important not only for energy loss but also for the thermal comfort and indoor air quality of the space (Balocco et al., 2008). Building insulation can be in the form of external insulation and internal insulation. Although external insulation is the common option that protects the existing structure from the external environment and eliminates thermal bridges, the protection and restoration of culturally valuable structures can be possible with internal insulation. The use of internal insulation is risky due to damages such as frost damage, mold formation, condensation at the interface, and salt efflorescence (Klõšeiko et al., 2017) (Zhao et al., 2017). In order to reduce the risk of damage and support the preservation of cultural heritage, vapour-open capillary active internal insulation systems that allow vapour exchange between the internal and external environments are encouraged (Grunewald et al., 2006; Remmers 2014; Vereecken & Roels, 2015).

The systems currently marketed as capillary active cannot be comprehensively evaluated through a generalized analysis based on a single standard system. This highlights the need for more detailed and specific approaches that consider the multifaceted performance characteristics of such materials. Accordingly, this study aims to contribute to defining the necessary thresholds for enhancing the hygrothermal performance of capillary active insulation materials, while maintaining low thermal conductivity, and to support the development of multifunctional insulation materials suitable for use in the building sector.

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2. Capillary active insulation materials and parameters affecting their performance

Capillary active insulation materials are vapour permeable systems that prevent condensation at the interface thanks to the capillary forces of the insulation material, but also allow drying. These systems aim to dry out the original wall by allowing the condensation occurring at the interface between the wall layers to dry inwards. On the other hand, vapour impermeable systems can pose potential risks such as frost damage, increased moisture content in the wall and various structural damages, while traditional vapour open systems can lead to intermittent condensation (Vereecken & Roels, 2014). For this reason, the use of capillary active interior insulation systems has been encouraged. The working principle of capillary active interior insulation systems is as follows:

1.During the heating season, moisture moves from the inside of the wall to the outside due to the temperature and vapour gradient.

2.Condensation occurs when the temperature between the adhesive mortar and the insulation material drops below the dew point.

3.The capillary active insulation material absorbs the condensed water and carries it inwards following the capillary pressure gradient. Thanks to this mechanism, condensed water does not accumulate in the wall structure and the wall is allowed to dry.

The main reason for choosing capillary active systems, whose working mechanism is generally explained from the perspective of condensation at the interface, is that these systems have drying-allowing and vapour-permeable characteristics (Vereecken & Roels, 2016a) (Fig. 1).

Studies have shown that the use of vapour-open materials can increase hygrothermal performance (Finken et al., 2016; Klõšeiko et al., 2015; Marincioni & Altamirano, 2014; Morelli & Moller, 2019; Odgaard et al., 2018). Certain systems exhibit such low capillary absorption coefficients (and thus minimal liquid permeability) that they can scarcely be considered capillary active. This may lead to increased moisture accumulation on the warmer side of the masonry wall and in the adhesive mortar. However, it also reduces the risk of excessive inward moisture flow, such as during heavy wind-driven rain exposure. There are also studies where high humidity values occurred at the interface (Odgaard et al., 2018) (De Mets et al., 2017). When using capillary active insulation materials on the interior side of a wall, humidity-related concerns within the wall must be addressed. One key consideration is the compatibility between the insulation and the adhesive properties. Studies have been conducted to examine the effects of insulation and adhesive mortar on moisture distribution in the wall (Kočí et al., 2013) (Vereecken & Roels, 2016b).

The application method of the insulation material is also an aspect that requires attention. Interstitial condensation can be managed effectively, provided there is proper contact between the masonry wall and the insulation. For this, the insulation material should have lower vapour permeability, lower thermal conductivity and capillary conductivity values than the adhesive. If this is not the case, the adhesive prevents the water formed by condensation from being transmitted back. In cases such as existing building renovation and restoration, it can cause mold formation. (Fig. 2a).

Scheffler and Grunewald (2003) proposed a two-layered capillary active interior insulation system to prevent moisture-related issues in buildings, particularly when an air gap exists between the insulation and the masonry wall. This system uses a retarder layer (with higher thermal conductivity, lower capillary conductivity and higher vapour diffusion resistance than the insulation layer) close to the wall structure and an insulation layer (with lower thermal conductivity, higher liquid conductivity and lower vapour diffusion resistance than the retarder) on the room side. The increase in thermal conductivity of the retarder layer reduces the amount of vapour diffuses, resulting in less condensation in the old wall structure.

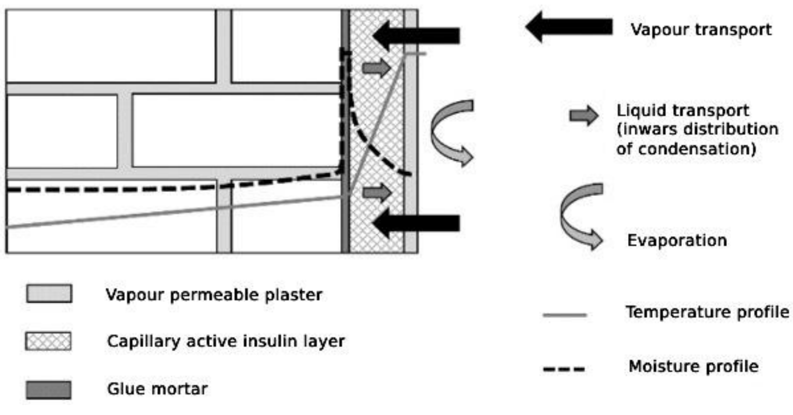


Fig. 1. Working mechanism of a standard capillary active insulation system (Vereecken & Roels, 2016a)

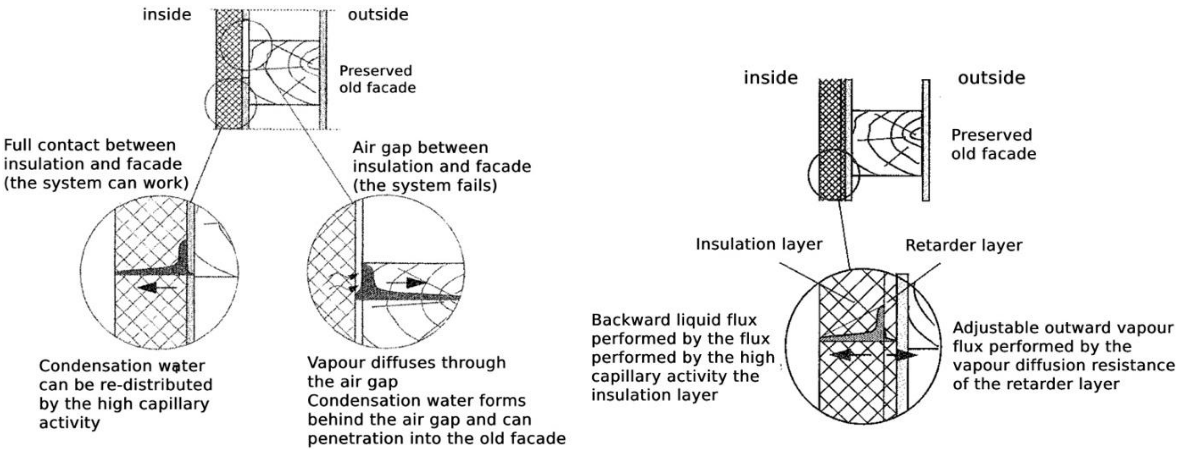


Fig. 2. Air gap problem between capillary active materials (a) and the wall and proposed system (b) (G.Scheffler & Grunewald,2020)

Table 1. Performance comparison of capillary active and traditional vapour-tight internal insulation systems

Capillary Active Systems	Vapour Tight Systems
Lower thermal resistance	Higher thermal resistance
Water vapour diffusion factor is low	Water vapour diffusion factor is high
High water absorption coefficient	Low water absorption coefficient
Allows moisture to move easily from the wall to the room	Prevents moisture from moving from the wall to the room.
Recommended for wooden beam ends in historic buildings	Not recommended for wooden beam ends in historic buildings
Higher indoor relative humidity during the heating season	Lower indoor relative humidity during the heating season
Rain load from wind affects the relative humidity of the interior surface	Rain load from wind does not affect the relative humidity of the interior surface.
Wind-driven rain load affects thermal resistance more	Wind-driven rain load affects thermal resistance less
It performs better on thick walls or walls that are protected against wind-driven rain loads	Performs less effective, "worse" on thick walls or walls protected from wind-driven rain loads

This design encourages condensation to form between the two layers, rather than in the wall structure, so that the insulation layer can manage moisture and protect the structure from potential damage, particularly mould growth. As a result, this system offers a vapour permeable and thermally efficient internal insulation solution. It also allows air gaps to be createdadhes between the insulation and the existing façade, without its performance being affected by the bonding methods used (Fig. 2b).

A comparison of the performance of capillary active and traditional vapour-tight internal insulation systems is given in Table 1.

Capillary active insulation systems perform better than vapour-proof systems if they are applied to a sufficiently thick wall or a wall protected from rain. If the wall is thin or exposed to rain, the moisture diffusing inside may cause undesirable situations. Some of the moisture will be stored while some will disperse into the room. This will cause a decrease in the performance of the insulation material when the indoor relative humidity is high (Vereecken & Roels, 2015).

3. Performance requirements of capillary active insulation material

Upon reviewing the literature, it was observed that no qualitative criteria have been established to characterize the hygroscopic and thermal properties of capillary active insulation materials. A methodology was proposed for classifying the hygroscopic properties of insulation materials to facilitate the selection of appropriate insulation for the envelopes of historical buildings (Posani et al., 2021a). High vapour permeability, low thermal conductivity and the ability to transfer moisture in liquid form at low humidity levels are the three physical properties that an active insulation material must have. One of the basic elements that determine the working principle of the systems is the property defined as capillary activity in the literature (GA Scheffler, nd).

3.1 Moisture content

In the analysis of moisture accumulated in wall assemblies, a systematic distinction is made between moisture accumulated in the wall structure outside the insulation system and the surface finish layer and moisture accumulated within the insulation system. When the effect of wind-borne precipitation is excluded from the evaluation, the amount of moisture in the load-bearing brick layer is generally negligible. However, in capillary active systems, a certain amount of moisture accumulates in calcium silicate and adhesive mortar. In contrast, in systems using XPS, either no moisture accumulation is observed or it is much less (Finken et al., 2016). Since moisture accumulation can cause a decrease in thermal resistance, it should be taken into account in thermal performance analyses.

3.2 Water absorption coefficient

When the material is in direct contact with water, the water uptake resulting from capillary suction can be measured by the water absorption coefficient. It has been stated that capillary active insulation materials applied to building envelopes with porous and capillary active character absorb the liquid water formed as a result of condensation and buffer it to the interior space, thus ensuring the envelope dries (Vereecken & Roels, 2015). The importance of using insulation materials with similar hygroscopic properties to the existing wall in preserving the general drying capacity of historical materials and regulating the water absorption of the wall exposed to rain loads has been emphasized (Finken et al., 2016). When the water absorption coefficient values found in the literature for various insulation materials widely used in the refurbishment of historical buildings were compared, it was seen that inorganic materials (Mineral Wool, Calcium Silicate and Cellulose) had relatively high absorption coefficients (Posani et al., 2021b).

3.3 Thermal conductivity coefficient

According to the DIN 4108 standard, materials with a thermal conductivity coefficient (λ) below 0.1 W/(m K) are classified as thermal insulation materials in the construction sector. Materials with a λ value below 0.03 W/(m K) are considered to have high insulation performance, while those in the range of 0.03–0.05 W/(m K) are moderately effective; values above 0.07 W/(m K) indicate low insulation capacity (Jelle, 2011; Koru, 2016; Pfundstein, Gellert, et al., 2008). The ranges of the thermal conductivity coefficient for different material groups contain various uncertainties: for inorganic materials, this value generally varies between 0.03–0.07 W/(m K), while for organic materials it is 0.02–0.055 W/(m K), and for advanced materials, values mostly below 0.01 W/(m K). In general, the nominal thermal conductivity coefficient of porous materials varies between 0.02 and 0.08 W/(m K); for alternative insulation products based on natural fibers, this range is at the level of 0.04–0.09 W/(m K) (Hung Anh & Pásztory, 2021).

3.4 Vapour diffusion resistance factor

The higher the water vapour diffusion resistance factor of the insulation materials, the lower their moisture absorption capacity. A thermal insulation material with sufficient thickness and sufficiently high water vapour diffusion resistance should be selected to prevent condensation. When more than one layer of building material is used, the water vapour diffusion resistance of the building component should be calculated by considering the thickness and water vapour diffusion resistance factor of each material separately. If the water vapour diffusion resistance factor of the capillary active insulation material is lower than that of the adhesive mortar, the risk of condensation between the adhesive mortar and the insulation should be taken into consideration (Bademlioğlu et al., 2018; Insulation Materials-Properties, n.d.).

3.5 Bulk density

Density is highly correlated with thermal conductivity, vapour diffusion factor and water absorption. There are studies that thermal conductivity and vapour diffusion factor generally show a linear correlation (Conti et al., 2016; Costes et al., 2017). It has been determined that the water vapour resistance factor is lower in materials with lower density due to increased porosity (Marques et al., nd). Lebed and Augaitis (2017) modeled the relationship between the water vapour resistance factor and density (in the range of 60–180 kg/m³) by means of a polynomial function based on the data obtained by the wet cup method (Zhou et al., 2022). However, some studies have concluded that the water vapour resistance factor is not significantly affected by density, it is relatively insensitive to this parameter (Cascone et al., 2019; Marques et al., nd; Reif et al., 2016).

3.6 Spesific heat

Capillary active materials have a porous structure that affects water vapour and moisture transfer. Having a high specific heat ensures that surface temperatures remain more stable. This reduces the risk of condensation and prevents mold formation and material deterioration, thus increasing the durability and performance of the material. Having a high specific heat in capillary active insulation materials increases the material's capacity to store and slowly release heat(Gündüz et al., 2001).

4. Capillary active insulation materials

Nowadays, various capillary active materials are available for internal insulation improvement. Initially, most of the studies on capillary active internal insulation systems focused on calcium silicate-based systems that provide a large amount of capillary liquid transport with pore sizes ranging from 0.1–1 µm (Häupl et al. 2003; Grunewald et al. 2006; Vereecken and Roels 2014b; Vereecken et al. 2015; Scheffler and Grunewald 2003). Later, different types of capillary active internal insulation systems have been introduced. Examples are aerated concrete (e.g. Multipor®), mineral foam, wood fiber board (WFB), cellulose, capillary-active, diffusion-open wood fiber insulation, composite internal insulation system with PUR foam and mineral coating, PUR/VIP-Reinforced calcium silicate composite, etc. These materials have a wide range of properties and working mechanisms, as described below.

Recently, some researchers have also developed biodegradable capillary active insulation materials, such as sheep wool (Gu et al., 2020; Zach et al., 2012), hemp (Scrucca et al., 2020), flax (Benmahidddine et al., 2020), jute (Senbagan et al., 2020) and corn stalk (Ahmad et al., 2020; Ahmad et al., 2019; Ahmad&Chen 2020; Ahmad et al., 2018). These biomaterials are sustainable and offer hygroscopic and capillary active properties. However, there is insufficient research on their usability as capillary active insulation materials.

- CaSi

Calcium silicate foam (CS) consists of calcium and silicon oxide plus 3–6% cellulose aggregate as raw materials. By mixing these materials with water, calcium silicate hydrate (CSH) is produced. The cellulose content plays a role in increasing the flexibility and edge stability properties of the material. During the production process, the mixture is poured into pre-prepared molds and then subjected to an autoclaving process, where high pressure and steam are applied together. Following this process, the product is cut into sheets and the surface is treated with metallic soaps or siliconates to provide water-repellent properties. The resulting structure is in the form of a finely porous, open-celled and rigid foam (Pfundstein, Söffker, et al., 2008) (Fig. 3a).

- AAC

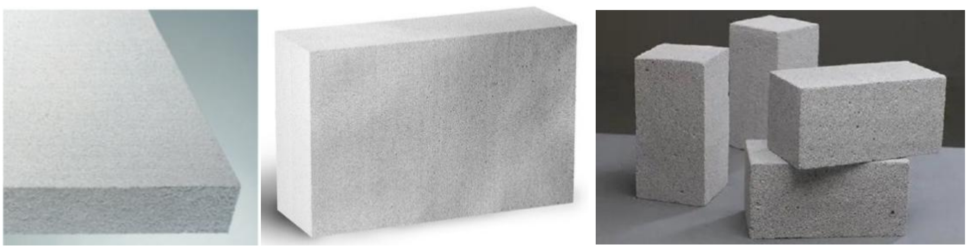
Autoclaved aerated concrete (AAC) consists of quartz sand, mineral lime and cement. The components are mixed by adding water and the expansion agent aluminum paste reacts with the alkali elements in the cement during the pre-curing process to form gaseous hydrogen. In the later stages of the production process, the hydrogen gas formed is released into the atmosphere and removed from the cavities in the block. Then, the material is subjected to an autoclaving process under high temperature and pressure for a certain period of time. After steam curing is completed, the material is dried with hot air to its final state and becomes ready for use (Mathey & Rossiter, 2009) (Fig. 3b).

- Mineral Foam

Mineral foam (MF) is produced from a mixture of lime, finely ground quartz sand, cement and a pore-forming component. The production process is similar to the production of autoclaved aerated concrete. However, the main difference is that natural protein-based foams are added to the mixture in order to provide a biologically sourced pore structure during the pore-forming stage. The organic components in these protein-based foams are decomposed and removed from the environment during steam curing during the autoclaving process (Zhou et al., 2022; Institute of Building Biology) (Fig. 3c).

- Wood Fiber Board

It consists of long-fibre softwood and sometimes hardwood wood fibres. Depending on the production method, wax-based emulsions containing latex or aluminum sulfate as binding material can be preferred. Boric acid is added to the production process to increase the resistance of the material to pests and fire. In addition, some wood types are treated with bitumen or natural resin-based emulsions to provide additional water-repellent properties. The production process begins with the wood raw material being first chopped into small pieces in a chipper; these pieces are then pulped in an autoclave and then pretreated between grinding rollers before being pulverized. The resulting pulp is pressed in molds and finally dried to obtain the final product (Pfundstein, Söffker, et al., 2008) (Fig. 4a).



a) b) c)

Fig. 3. a) Calcium silicate (CaSi), b) Aerated concrate (AAC), c) Mineral foam (MF)

a) b)

Fig. 4. a) Wood fiber board, b) Cellulose

- Capillary-active, diffusion-open wood fibre insulation system

It consists of system components of wood fiber, mineral functional layer, clay or lime plasters. The core material is wood fiber obtained from coniferous wood waste such as sawdust and woodchip. These fibers are processed by a thermomechanical method using lignin, the natural binding agent of wood. The mineral functional layer is a capillary active surface treatment that balances vapour resistance with breathability. It is available on the market under the trade name Pavatex Pavantro (Soprema United Kingdom) (Fig. 5a).

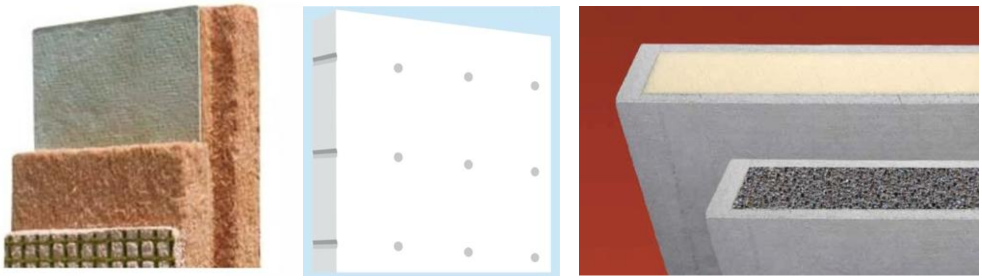
- Composite internal insulation system with PUR foam and mineral coating

This material, produced under the trade name IQ-Therm is a composite insulation material consisting of rigid polyurethane foam panels laminated with a mineral nonwoven layer, offering a synergistic solution for thermal insulation and moisture management in interior applications. This combination results in a capillary-active, diffusion-open insulation material that effectively balances thermal performance with moisture control. In such a system, if condensation occurs in winter due to temperatures dropping below the dew point, or if heavy rain penetrates the façade, with iQ-Therm the moisture is not retained behind a film, but is instead directed out of the wall section via the mortar and released back into the room air without causing damage (IQ-Therm 2.0) (Fig. 5b).

- PUR/VIP-Reinforced Calcium Silicate Composite

This material, produced under the trade name Calsitherm Xtra, is a composite insulation system composed of calcium silicate together with Polyurethane (PUR), pyrogenic silicas or VIP (Fig. 5c). It is formed in a reaction between lime (calcium oxide) and sand (silicon dioxide), under high pressure steam in an autoclave process. This process results in a microporous structure that is both breathable and moisture regulating. The fact that approximately 93% of the volume is air gives the material thermal insulation and moisture buffering ability. The high alkalinity of the material makes it naturally resistant to mold and eliminates the need for chemical biocides (CALSITHERM).

Table 2 shows the water absorption coefficient, thermal conductivity, moisture content, sd value, vapour diffusion resistance factor, bulk density, and specific heat values of capillary solid insulation materials, which are important for their hygrothermal performance, and have been investigated using literature findings.



a) b) c)

Fig. 5. a) Capillary-active, diffusion-open wood fibre insulation, b) Composite internal insulation system with PUR foam and mineral coating, c) PUR/VIP-Reinforced Calcium Silicate Composite

Table 2. Capillary active insulation material properties

Materials	Water absorption coefficient [kg/m²√s]	Thermal conductivity coefficient(λ) [W/mK]	Moisture content [kg/m^3]	sd for r=2.5 (m^{2}K/w) [m]	Vapour diffusion resistance factor (μ) [-]	Bulk density [kg/m^3]	Spesific heat [J/kgK]	Referance
CaSi Foam	0.95-1.07	0.045-0.065	20	1	3-20	115-300	1000- 1180	(Pfundstein et al., 2008)
AAC	0.006-0.008	0.042-0.045	25	0.55	6.7	98.5	1210	(Zhao et al., 2017)
Mineral foam	0.102	0.047	-	-	6.7	128.4	893	(Zhao et al., 2017)
Wood fiber board	0.07	0.042-0.09	30	0.47	5-10	40-270	1600-2100	(Pfundstein et al., 2008)
Cellulose	-	0.04-0.045	160	-	1.7-3	30-80	1700-2150	(Pfundstein et al., 2008)
Composite internal insulation system with PUR foam and mineral coating	0.013	0.031	-	2.25	39	-	-	(IQ-Therm 2.0)
PUR/VIP-Reinforced Calcium Silicate Composite	-	0.059	-	0.4	3	180-187	-	(CALSITHERM)
Capillary-active, diffusion-open wood fibre insulation	0.2	0.0443	-	0.95	5-12	180-700	1700-2100	(Soprema United Kingdom)
CS-1	2.92	0.11	-	4.42	16.07	662	1362	(Ahmad et al., 2021)
CS-2	1.82	0.06	-	1.78	11.85	598	1607	(Ahmad et al., 2021)

It has been observed that the water absorption coefficient of Autoclaved Aerated Concrate is relatively low compared to other alternatives. This situation may be insufficient in terms of liquid permeability when compared to CaSi Foam. Thermal conductivity levels are lower than the required 0.1 W/(mK) except for the CS-1 alternative. Since the vapour diffusion values are low, the Sd values are lower than those of traditional insulation materials. The vapour diffusion resistance factor of Composite internal insulation system with PUR foam and mineral coating is relatively higher. The vapour resistance factor of other insulation materials should also be improved to a level that will allow vapour to pass through but will not allow condensation at the interface. It has been observed that density levels sometimes match or exceed the desired 50-70 kg/m3 level in foam insulation materials (Mühendisleri et al.). The densest materials were CS-1 and CS-2, which were suggested as composite capillary active alternatives. Specific heat of natural fiber insulation materials generally provided the range of 800-1200 or higher.

The comparison of the property range of capillary active insulation materials with the traditional insulation materials (glass wool, stone wool, PUR, XPS, EPS) which are based on standard industry ranges are given in Table 3.

Table 3. Comparison of the property range of capillary active and traditional insulation materials.

Material	Thermal Conductivity (λ) [W/m·K]	Moisture Content [kg/m³]	Diffusion Resistance Factor (μ) [-]	Bulk Density [kg/m³]	Specific Heat [J/kg·K]
Capillary Active	0.031–0.11	20–160	1.7–39	98–662	893–2100
Glass Wool	0.032–0.040	<1	1–2	10–50	840
Stone Wool	0.033–0.040	<1	1–2	30–150	840
PUR	0.022–0.028	<0.5	30–100	30–50	1400
XPS	0.030–0.038	<0.5	100–200	25–45	1300
EPS	0.030–0.040	<1	20–70	15–30	1300

Capillary active materials are designed for moisture management, which makes them heavier and more moisture-absorbent compared to traditional insulation materials, with a moisture content of 20–160 kg/m³ versus <1 kg/m³ for glass wool, stone wool, XPS, and EPS, and <0.5 kg/m³ for PUR. Their water absorption coefficient ranges from 0.006–2.92 $kg/m^2 \cdot s^{0.5}$, significantly higher than traditional materials like PUR, XPS, and EPS (0.013 $kg/m^2 \cdot s^{0.5}$) and glass wool and stone wool (0.7 $kg/m^2 \cdot s^{0.5}$), reflecting their ability to actively manage water. They can match the thermal performance of glass wool, stone wool, XPS, and EPS at their best (0.031–0.040 W/m·K), but PUR outperforms them in insulation efficiency (0.022–0.028 W/m·K). Their vapour permeability is moderate, with a diffusion resistance factor (μ) of 1.7–39, compared to 1–2 for glass wool and stone wool, and 20–200 for PUR, XPS, and EPS, making them suitable for specific applications where moisture regulation is critical.

5. Conclusion

With the increasing importance of energy savings, there will be a greater need for capillary active insulation materials in the near future.

Capillary active materials, designed for moisture management, are heavier and more moisture-absorbent than traditional insulation materials like glass wool, stone wool, PUR, XPS, and EPS. They exhibit a higher water absorption coefficient, reflecting their ability to actively manage water, compared to the lower absorption of traditional materials. Their thermal performance can rival that of glass wool, stone wool, XPS, and EPS, though PUR offers better insulation efficiency. With moderate vapour permeability, capillary active materials are well-suited for applications where moisture regulation is essential, unlike traditional materials with varying degrees of vapour resistance.

The application method of capillary thermal insulation material is one of the aspects that requires attention. In traditional internal insulation systems, to prevent condensation within the cross-section, the vapour diffusion resistance factor (μ) of the material layers should decrease from the inner surface of the wall towards the outer surface. In capillary active systems, however, the insulation is fixed with an adhesive mortar that has higher thermal conductivity and lower vapour permeability than the insulation material, ensuring that the condensation layer remains on the insulation material side. This system can provide a vapour-permeable, thermally effective interior insulation solution.

The development of novel capillary active insulation materials presents significant challenges. It requires producing a single panel, derived from a uniform insulation material, that combines multiple properties, including capillary activity, thermal insulation, and adjustable vapour permeability. Additionally, the panel must be easily applicable, incorporating an air gap between itself and the existing structure, while maintaining effective insulation within practical thickness constraints. Innovative composite materials with hygrothermal performance compatible with the properties of capillary active insulation materials can be developed using bio-based or polymer waste fibers, lightweight waste aggregates, or foamed inorganic binders. Additionally, studies are needed to evaluate the long-term durability and environmental impact of these composites, as well as to optimize their composition and processing properties.

In future research, if studies comparing the hygrothermal performance calculated through simulations with the actual on-site performance of an insulated structure become more widespread, the assumptions about capillary active insulation materials will become clearer.

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Improving the thermal comfort of traditional housing by adapting a high-performance material

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Abstract. The use of built with earth (Adobe) materials in Algeria is a very old tradition. The present work purpose was to improve the mechanical and thermal resistance of Adobe bricks, as well as to demonstrate the advantages of their use in buildings in the Sahara. Three clay samples were chosen from three different traditional houses in Zgag El Hadjaj ksar in Laghouat, south of Algeria. Two types of clay bricks were made from these three samples: bricks M1 (80% soil plus 20% clay) and M2 (70% soil plus 30% clay) According to the literature review, the M1 and M2 bricks were tested to study the effect of the mixture's combination on the physical, mechanical, and thermal properties of the adobe bricks. The laboratory test shows that bricks M2 give the best properties; in order to improve the M2 bricks properties, the following percentage is needed: 0%, 0.1%. 1.5% and 2% of straw with a length between 2 and 5 cm were added to the mixture. The experimental results showed that the mixture containing 2% straw was the most effective and improved the thermal conductivity from 0.71 w/m². k. to 0.51 w/m².k. compared to one without straw. These ratios of 2% of straw in the mixture increase the compressive strength from 19 bars to 32 bars, which is within the scope of the literature. The study shows the clay brick made with M2 mixture and 2% of straw with a thermal conductivity of 0.51 w/m². k. can produce the same thermal performances during summer time with less thickness from 60 cm to 40 cm and give the same inside air temperature in the space.

Keywords: Earth architecture; Thermal comfort; Thermal inertia; Ksar of Laghouat; Clay material, Courtyard

1. Introduction:

Earth construction has been one of the techniques used extensively in construction in different historical ages. Man began to use earth construction at least 6000 years ago in Mesopotamia, and it has been used much more by different civilizations all around the world. Nowadays, it is estimated that between 30% and 50% of the world's population lives in earth structures, where earth construction techniques are still predominantly used for new housing, mainly to ensure comfort to the occupants and architectural compatibility with historically established environments**.** (Hui Xi and al. 2024) investigated the indoor thermal comfort in traditional dwelling and new residences during summer time, they found that traditional house indoor temperatures were acceptable, due to buildings envelope materials. (Ines Costa-Carrapico and al. 2022) evaluated the thermal comfort in vernacular dwellings in Portugal, the study found that the summer thermal comfort reached in naturally ventilated vernacular houses. (Mahmoud Murtata Farouq and al. 2024) examine the integration of phase change material into earth wall to improve its thermal performance, they found that the integration of PCM offers a promising solution to enhance thermal comfort. (Amal Chkeir and al. 2024) studied the thermal comfort in traditional and contemporary houses in Lebanon, their results show that traditional houses perform better in terms of thermal comfort, due to their use of natural and passive methods.

This study presents the results of an experimental work carried out on raw earth materials with 0 to 2% of weight of barley straw. Straw is a local agricultural waste was used to improve the material thermos-physical properties. Mechanical and thermal properties were thus measured to enrich the databases of earth biomass construction materials. The mean Aime of the study was to make a comparison between the old material (adobe), and the improved ones in order to evaluate the thermal efficiency of the two materials and to find the optimal wall thickness that can be achieved with the new brick, and this according to the material thermal resistance.

2. House description model:

In order to study the envelope effect on the building thermal behavior, a house in traditional architecture design was studied. The spatial organization of this house revolves around a central courtyard on the ground floor see fig. 1, where living spaces, 03 bedrooms, living room and kitchen are located. Upstairs, the 3 bedrooms also open on to the central

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patio. Access to the upper floor is via 3.00 m-high staircases, which are located in the middle of the patio. The presence of vegetation around the courtyard softens the temperature of the air inside.

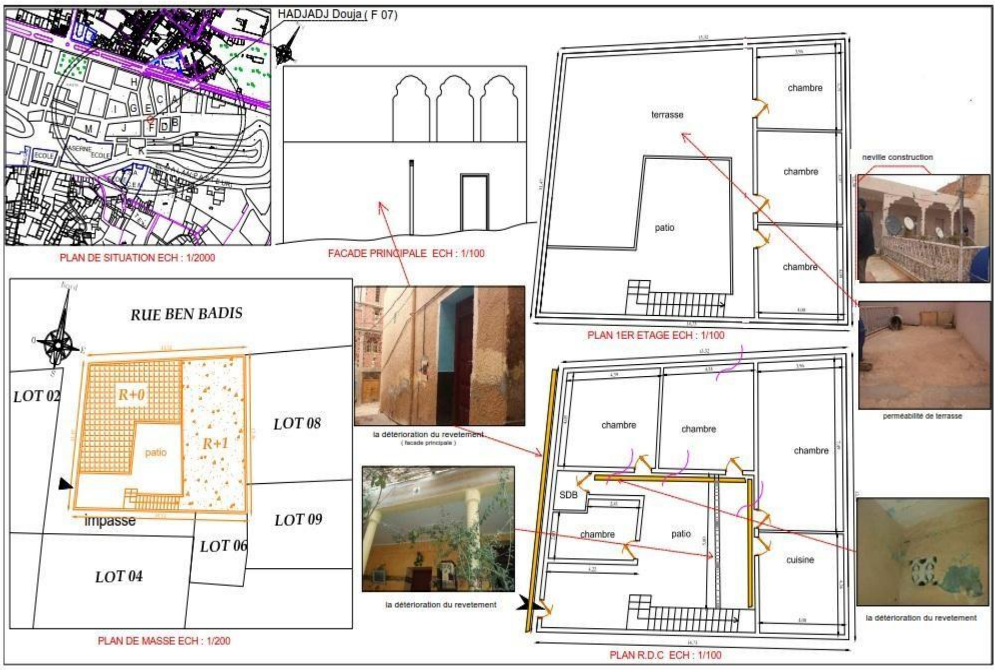

Fig. 1. The simulated house floor plans

The load-bearing adobe walls are 3.00 m high on each level. The characteristics of the envelope of this dwelling are:

- The exterior walls are double-walled with 60 cm-thick mud bricks.
- The interior walls are single-wall mud brick, 40 cm thick.
- Exterior and interior rendering are lime mortar.
- The roof is composed of a traditional slab made up of different layers of lime whitewash and lime mortar, a layer of clay soil, a layer of reed matting and palm trunk beams.
- Adobe is a local product made from malleable local earth, water and a little straw. The mixture is agglomerated in a parallelepiped Mold. Once dry, it is used to build the wall.

3. Measured parameter:

The brick of dimension (28x12x8cm) cut by shearing device in order to take the test pieces of (5.5.5 cm) which will be subjected to crushing. These tests are carried out on the pilot bricks of earth M1 and M2 aged 28 days and stabilized with the following fiber contents: 0%, 1%, 1.5% and 2% straw. These tests were carried out on bricks of dimensions 5. 5. 5 cm using the two mixtures of earth with: - Four fiber rates: 0%, 1%, 1.5%, 2%, for Adobe M1 and M2. The dimensions of the fibers vary between 2 and 5 cm and the water content used in the mixture was 19%. In addition to the fiber content, the day of crushing was taken into consideration, for M1 and M2Adobe, the compressive strength was determined after 30 days which is the curing period required for the brick to acquire sufficient strength and the influence of the fiber content on this period.

The variation of compressive strength as a function of the straw percentage is shown for the raw earth brick M1 and M2 in Fig. 2, It is noted that despite the nature of the material used (earth) and the random distribution of the fibers, the correlation coefficient of the lines obtained in the interpolation of the experimental points is acceptable (R = 0.85), and the curves given in the fig. 3 and 4, for the other earths show that there is an optimal percentage of fiber corresponding to the maximum compressive strengths of the bricks. When its optimal fiber contents are equal, 2% for earth M1 and M2.

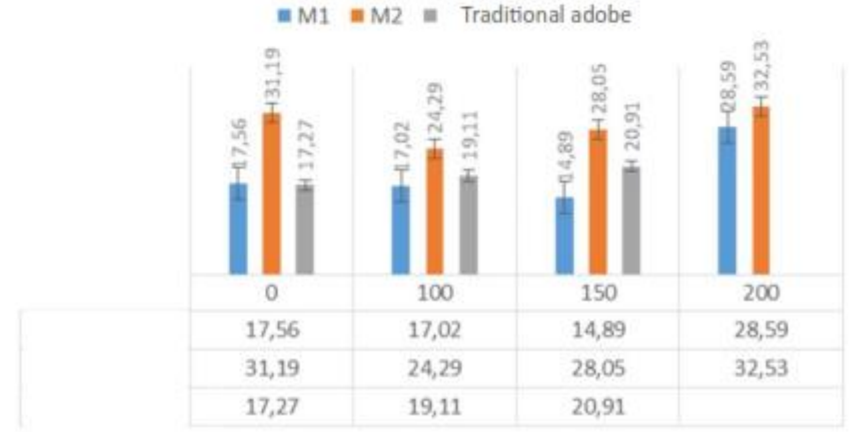

Fig. 2. New and traditional Adobe strength

4. The main methods of measuring thermo-physical properties:

The two types of earth bricks M1 and M2 were characterized at the laboratory scale. Their thermo-physical properties were determined and presented in the tables (1 and 2) and figures (3 and 4). The improvement of adobe; the making of new adobe;

M1= 80% soil+20% Sofabril clay + X % straw. M2= 70% soil +30 % Sofabril clay + X% straw.

Table 1. Sample M1 thermo-physical properties

Sample	M 1+0%	M1+1%	M1+1.5%	M1+2%
Dimensions L × l × h (mm)	280×120×80	280×120×80	280×120×80	280×120×80
Density (kg/m3)	1488	1482	1413	1394
Thermal Conductivity (W/m.K)	1.01	0.88	0.84	0.54
Specific heat (J/kg.K)	1.00	1.34	0.94	1.02
Thermal Diffusivity (10-7 m²/s)	0.88	0.75	0.58	0.82
Thermal Effusivity (J.K-1.m-2.s-1/2)	5.93	6.72	5.89	7.02

Table 2. Sample M2 thermo-physical properties

Sample	M 2+0%	M2+1%	M2+1.5%	M2+2%
Dimensions L × l × h (mm)	280×120×80	280×120×80	280×120×80	280×120×80
Density (kg/m3)	1499	1507	1433	1393
Thermal Conductivity (W/m.K)	1.04	0.82	0.77	0.51
Specific heat (J/kg.K)	1.58	1.53	1.78	0.85
Thermal Diffusivity (10-7 m²/s)	0.66	0.50	0.46	0.60
Thermal Effusivity (J.K-1.m-2.s-1/2)	6.28	6.35	6.06	5.99

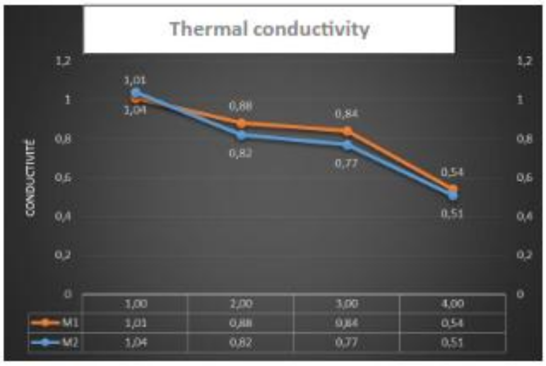

Fig. 3. Adobe M1 and M2 Thermal conductivity

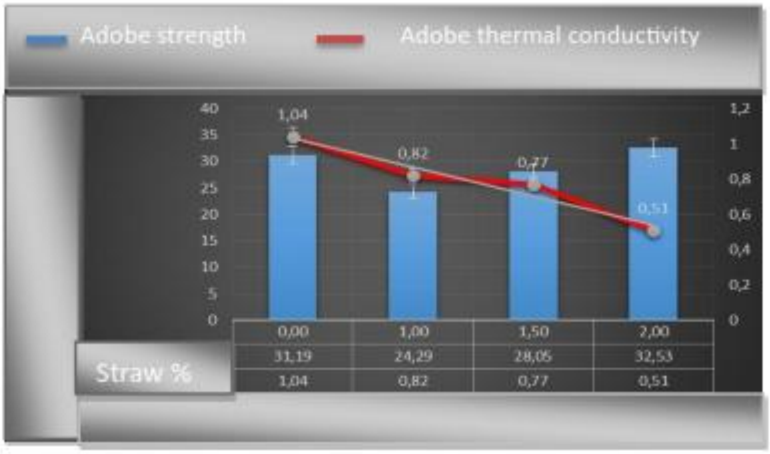

Fig. 4. Adobe M2 thermal conductivity and Compressive strength variation with straw percentage

5. The optimal composition:

From the above figures, the compressive strength and the thermo-physical properties of the different mixtures of raw earth and straw, the adobe M2 plus 2% straw give the high compressive strength of 32.50 bars and low thermal conductivity of 0.51 w/m².k., this adobe was selected to carry out the study.

The current work aims to study the effects of thermo-physical properties of this type of raw earth bricks by experimental research, and their dynamic thermal execution (thermal capacity, time lag and decrement factor) depending on the wall thickness. The objective is to determine the ideal thickness of a raw earth wall, established by these bricks, to achieve the optimum values of thermal inertia. These bricks were produced manually in the laboratory and the used process was by recycling the old adobe from demolished walls in the old city of Laghouat Zgag el hadjedj district. The main difference between the two types of bricks is the amount of added clay that was extracted from Mraigha quarries for the manufacture of baked clay bricks and the percentage of straw. They were characterized to determine their physical and geotechnical properties, and to identify their impact on the development and production of raw earth bricks.

6. Thermal resistance:

The thermal resistance of a material characterizes its capacity to slow down heat transfer by conduction. It is the ratio between the thickness of the material and the coefficient of thermal conductivity in (m^2.K)/W.

7. Assessment of the optimal wall thickness:

In the old city of Laghouat the outside wall thickness was 60 cm and sometimes exceeds made by adobe, the exterior walls in raw earth brick 60 cm and a thermal conductivity of 0.71 w/m.°k. the total thermal resistance is equal to 0.860 m² °k/w before improvement. The new improved adobe M2 plus 2% of straw with 0.51w/m°k thermal conductivity can give the same thermal resistance of 0.860 m² °k/w by only 42.6 cm of thickness. A theoretical study by simulation is conducted in order to appreciate the thermo-physical behavior of the adobe studied for the construction of an exterior wall in arid regions. Two different parameters have been varied in this study: the thickness of the wall, and the thermo-physical properties of the studied adobe made with M2 plus 20% straw.

The time lag ф, decrement factor *ƒ* and sol–air temperature are very important parameters to determine the heat storage capabilities of any material. The time takes a heat wave to propagate from the outer surface to the inner surface is named as ''time lag'' and the decreasing ratio of its amplitude during this process is named as ''decrement factor''. The schematics of time lag and decrement factor are shown in Fig. 5. In this study, the time lag and decrement factor are computed as follows. The time lag is defined as (H. Asan & Y. S. Sancaktar, 1998 and H. Asan, 2000)

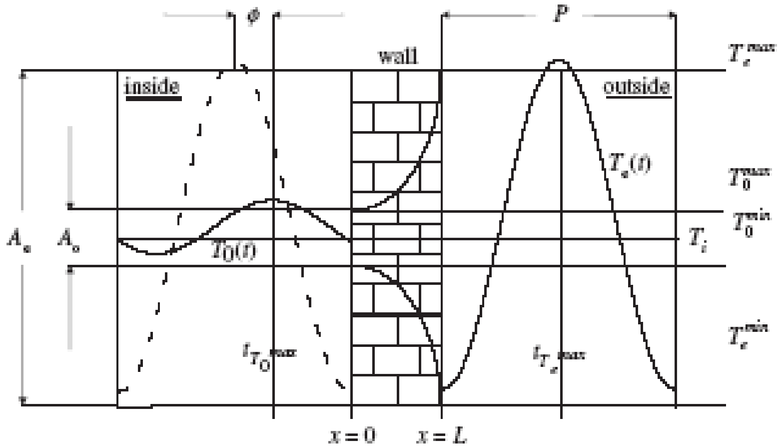

Fig. 5. The schematic representation of time lag ф and decrement factor ƒ

$$\phi \begin{cases} t_{T_0}max > t_{T_e}\max \rightarrow t_{T_0}max - t_{T_e}\max \\ t_{T_0}max < t_{T_e}\max \rightarrow t_{T_0}max - t_{T_e}\max + P \\ t_{T_0}max = t_{T_e}\max \rightarrow P \end{cases} \quad (1)$$

where **t** $(\boldsymbol{Tse_{max}})$, **t** $(\boldsymbol{Tsi_{max}})$ and (h) represent the time in hours when inside and outside surface temperatures are at their maximums, respectively, and P (24 h) is the period of the wave. The decrement factor is defined as,

$$f = \frac{A_0}{A_e} = \frac{T_0^{max} - T_0^{min}}{T_e^{max} - T_e^{max}} \quad (2)$$

Where A_o and A_e are the amplitudes of the wave in the inner and outer surfaces of the wall, respectively. The sol–air temperature, Tsa, includes the effects of the solar radiation combined with outside air temperature and changes periodically. This temperature is assumed to show sinusoidal variations during a 24-h period. Since time lag and decrement factor are dependent on only wall.

8. Results and Discussions:

During winter time fig. 6. below, the graph shows that the outside temperatures have a high amplitude of 14°C between the maximum value (21°C) recorded at 3:00 p.m. (in the afternoon) and the minimum value (6°C) recorded around 5:00 a.m. (in the morning). On the other hand, the ambient temperatures of the patio and those of the upstairs bedroom are almost constant, with amplitudes of around 2°C, unlike the temperatures recorded in the ground floor bedroom which approximately follow the path of the outside temperature curve, which give a time lag of 5 hours and a decrement factor of 0.067. The stability of the temperatures marked during the first ten hours in the patio (about 12 °C) is reflected by the damping of external contributions (whose temperatures fluctuate between 6 and 14 °C) ensured by the adobe brick (Motari, N., 2008), delaying the transfer of cold through the walls for six hours (from 6:00 AM to 12:00 PM) thanks to its thermal inertia and its thickness. This damping had a negative impact on the thermal behavior of three spaces evaluated during the afternoon, whose external temperatures were more pleasant, reaching the comfort range set by Givoni between 20 and 27 °C, around 2:00 PM

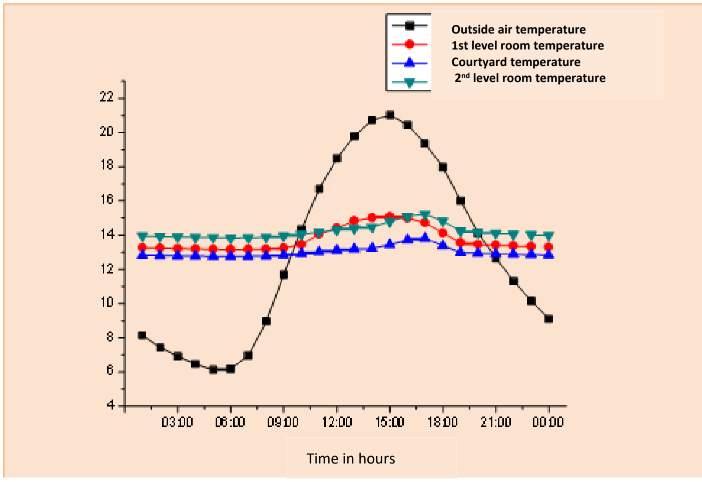

Fig. 6. Traditional adobe, Winter Inside spaces and outside air temperatures

During summer time, the results obtained from fig. 7, presented below show the temperature variation between the outside and the inside, the highest temperature difference of 10 °C was recorded in the upstairs bedroom around 3:00 PM, with a maximum outside and inside temperatures were respectively 45 °C and 35 °C. The minimum outside and inside temperatures were respectively 22°C and 32°C, which give a time lag of 5 hours and decrement factor of 0.087. These results are justified by the material's ability to store heat during the day and release it at night. (D. Medjelakh and S. Abdou 2008), However, this high thermal capacity of the material used causes an overheating, but the use of night natural ventilation can cool the mass of the building. in order to evacuate the hot air accumulated in the space during daytime to be cooled. This is clearly established according to the temperatures of the patio, which presents the most and least pleasant space (whose average temperature is 32 °C). Nevertheless, this temperature remains higher than the comfort range mentioned above.

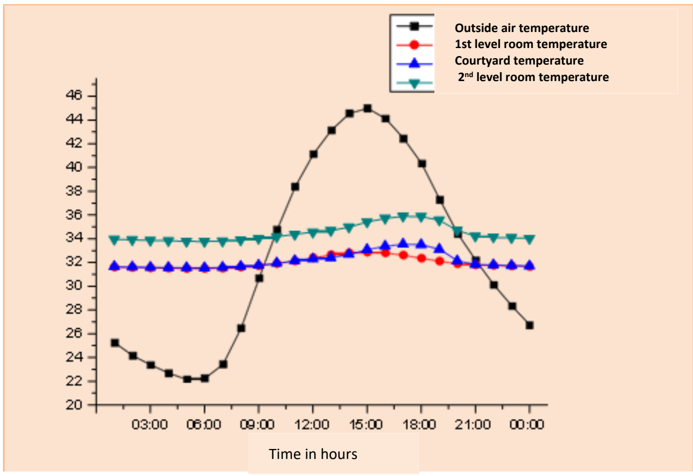

Fig. 7. Traditional adobe, Summer Inside spaces and outside air temperatures

8.1 The effect of improving the thermal conductivity of adobe

The improvement made on the thermal conductivity of the adobe allowed to optimize the thermal performance of the house, despite the reduced thickness of the wall (from 0.6 to 0.4 m). From fig. 8, an increase in ambient temperature was marked in all the spaces evaluated, with an average of 0.3 °C, in the typical winter day. From fig. 9, However, a stability of interior temperatures was marked after the improvement of the material in the summer period, whose thermal resistance was preserved, depending on the wall thickness and thermal conductivity (0.51 w.m/K).

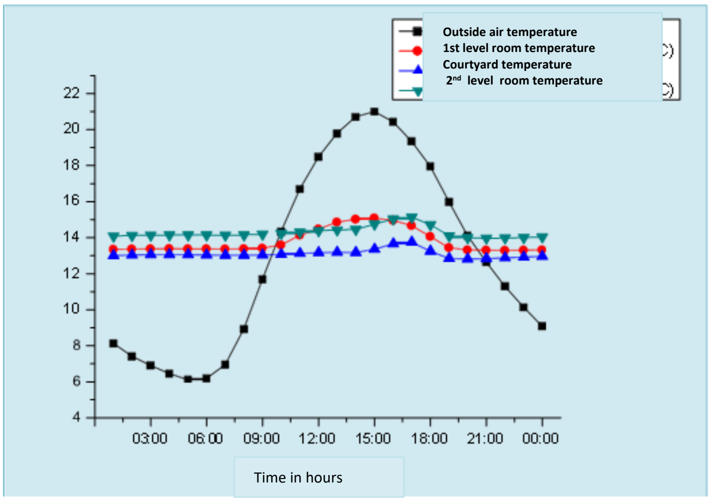

Fig. 8. Improved adobe, Winter Inside spaces and outside air temperatures

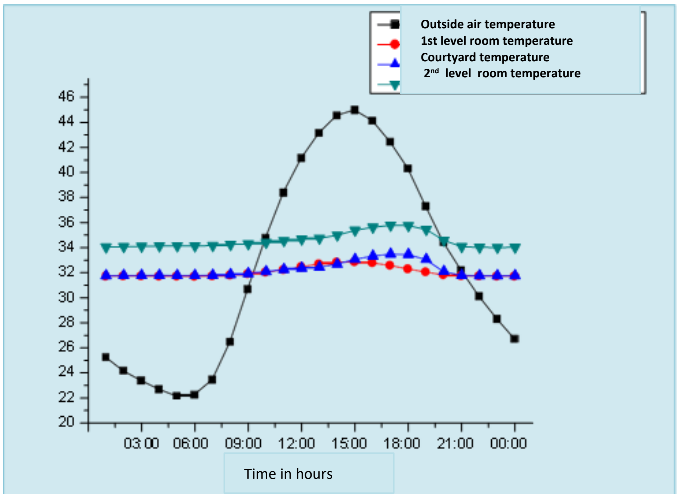

Fig. 9. Improved adobe, Summer Inside spaces and outside air temperatures

Comparing the results of this simulation (after the improvement) with the comfort range set by Givoni (20-27 ° C), it is shown that the thermal behavior of the house studied is outside the comfort range, whose average winter temperature is approximately 13 ° C and that of summer is equal to 33 ° C. Thermal inertia and night ventilation are the recommended solutions under the climatic conditions of June in the city of Laghouat. Night ventilation was neglected during the simulation, which justifies the summer results obtained, (S. Abdou and M. Boumaza, 2004)**.** On the other hand, all the parameters influencing thermal comfort were taken into consideration during the evaluation of the winter thermal behavior of the house, this shows that the results of the typical winter day reflect the real behavior of the spaces evaluated.

9. Conclusion:

Earth architecture is misunderstood and despised because it is linked to images of archaism and poverty. For nearly 9,000 years, man has tended to build cities entirely in raw earth and remains one of the most widely used building materials on the planet. This remarkable universal cultural heritage has been hidden since man has known the technique of transformations. We must therefore rediscover the evidence of what some have believed to be synonymous with poverty and precariousness. It is in this context that work on earth as a material has been undertaken by certain pioneers such as François Cointeraux and Hassan Fathy. The latter have given confidence to designers and others that it is indeed possible to build in earth. The revaluation of earth architecture must involve shedding light on a more in-depth knowledge of the material. In order to master it and highlight all its ecological virtues and thermal performances, with all the positive impacts that it can achieve on the energy, environmental and aesthetic level. In developing countries, the search for solutions to the problems posed by housing has become difficult due to an unfavorable economic context. In Algeria, the use of earth is a very old tradition. It was used not only in the countryside, but also in cities and Ksour. Currently, despite the trend towards using cement concrete, more than 50%

of the homes in the Algerian Sahara are still in "Toub". Almost all so-called traditional constructions are made with earth combined with other additional materials such as plant (straw and others) or mineral additions. In recent years, we have witnessed an interesting surge in research on so-called traditional materials. We are looking for affordable housing due to the scarcity and excessive cost of housing for developing countries, especially Algeria, where architects were convinced that the solution was in the past. However, the problem that raises some concerns is the improvement of its durability when subjected to deleterious climatic conditions. Indeed, much remains to be done to improve the poor image that earth construction currently offers and to develop an appropriate technique intended to lay the foundations for the promotion of this material and a future guarantee of well-adapted quality.

However, the determination of the dynamic thermal performance of these bricks showed the advantages of raw earth and its contribution to comfort. Indeed, the study showed that a thickness of 40 cm for M2 + P = 2% bricks, a stability of interior temperatures was marked after the improvement of the material in the summer period whose thermal resistance was preserved, depending on the wall thickness and thermal conductivity (0.51 w.m / K). This part of the work aimed to evaluate the thermal performance of the old building material (adobe) after improving its thermal conductivity, in order to reduce the wall thickness while preserving the same quality of the interior environment of the house under study. The results showed that the improvement made it possible to optimize the thermal comfort of the Ksourian dwelling during the winter period, and to preserve the same performance during the summer. However, these results were outside the comfort range, for this, an improvement was proposed in order to improve winter thermal comfort. The addition of a nylon cover at the patio level made it possible to increase the interior temperature, with a difference of 2 ° C between the two improvements. This cover is often used by the inhabitants of the old Ksar of Laghouat during the winter period, in order to remove it during the summer to let the air cool. The simulation carried out on a type of traditional house with a patio, these simulations made it possible to observe the role of this material in damping fluctuations in outdoor temperatures and in stabilizing the interior temperature. The latter which does not reach 32 ° C, during the summer months, thus limiting overheating of the house. This project has promoted the development of raw earth construction in the protected sector. It has now allowed the company to start some major construction projects.

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Evaluation of lightweight steel construction systems as an alternative to conventional construction systems

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Abstract. Light steel building systems are constructed using galvanized sheet steel profiles that are suitable for cold forming and feature lower carbon content compared to structural steel. Their prefabricated nature enables faster construction processes than conventional methods, making them an increasingly attractive option for modern building needs. Conventional systems often struggle to meet the growing demands for sustainability, rapid construction, and economic efficiency. In this context, light steel systems offer notable advantages such as flexibility in design, speed of assembly, and suitability for various building types. This study provides a comprehensive overview of the characteristics, design principles, and global applications of light steel structures. It also discusses the comparative advantages and limitations of light steel systems relative to conventional building methods. Through a review of existing literature, technical guidelines, and standards, the study highlights how light steel systems contribute to addressing contemporary challenges in construction. By examining different regional practices, the study aims to offer an insight into the current status and future outlook of light steel structures in the global construction market.

Keywords: Light Steel Construction; Conventional Construction; Sustainability; Structural performance; Architectural flexibility; Economic Efficiency

1. Introduction

The construction industry faces numerous challenges globally, including the increasing demand for sustainable practices, faster construction processes, and the necessity for structures that can withstand seismic events. These problems are especially pertinent in earthquake prone areas, where building safety and resilience are of utmost importance. Previously, construction practices have depended on the use of materials like concrete, brick, wood, and stone. In spite of centuries of such success for these materials, they have limitations including greater environmental impact, increased construction duration, and similar levels of seismic performance.

Light steel construction systems have been recognized as a promising substitute for conventional construction techniques. The systems provide numerous benefits including decreased construction time, better seismic resistance, and greater sustainability thanks to steel recyclability. Despite these benefits, the global adoption of light gauge steel building systems has been uneven, and comprehensive studies comparing their performance with conventional methods in various contexts have been limited.

This study aims to address this gap by conducting a global comparative analysis of the sustainability and seismic performance of light gauge steel building systems and conventional construction methods. The study will focus on key regions, including Europe, North America, and Asia, where these systems have been implemented to varying degrees. Through this analysis, the research seeks to provide insights into the advantages and challenges associated with lightweight steel construction, thereby contributing to the broader discourse on sustainable and resilient building practices. Through knowledge of the comparative benefits of lightweight steel systems, stakeholders in construction are able to make more informed choices, and this could reflect in higher adoption of the systems in regions where conventional methods still dominate. The research is not only timely but also critical in global efforts towards enhancing the sustainability and resilience of the built environment.

2. Material and Methods

This study presents a comparative evaluation of lightweight steel and conventional construction systems, focusing on sustainability, seismic performance, and economic efficiency. It is based on existing literature and building codes. The systems analyzed include reinforced concrete, timber framing, heavy steel structures and light steel systems made of cold formed, thin walled steel sections. They are reviewed in terms of structural behavior,

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construction processes, and environmental impact. The methodology relies on a literature review using academic databases. Additionally, construction practices from Europe, North America, and Asia were examined to understand practical applications

3. Conventional Construction Systems

3.1 Reinforced Concrete Systems

Concrete and reinforced concrete are widely used throughout the world, especially in the United States and Canada, as the primary structural building material. Concrete, also known as "man-made stone," is made by mixing cement, sand, aggregate and water, and can be molded into almost any shape when it has a plastic consistency. This flexibility enables flat slabs or panels to serve the dual purpose of a load-carrying structure and a finished floor or ceiling surface. Concrete developed in the 19th century, when Portland cement was discovered, has low tensile strength; steel reinforcement embedded in the concrete to improve strength in this direction gives ductility and moment stability to the structure by resisting tensile forces after cracking. Modern reinforced concrete design was shaped by the work of European engineers in the late 19th century and is now widely used in critical engineering projects such as buildings, bridges, and dams (Yakut, n.d.).

Reinforced concrete structures are made up of interconnected members that work together to bear the loads placed on them. For instance, the second floor in Fig. 1 uses concrete joist-slab construction. A series of parallel joists support the weight of the upper slab. The forces from these joists are transferred to the beams, which are then supported by columns. The ductility provided by steel reinforcement during earthquakes increases structural safety. Another advantage of reinforced concrete systems is that they provide 1-3 hours of fire resistance without the need for additional fire insulation. Additionally, the wide availability and ease of transporting materials like sand, gravel, crushed stone, water, cement, and reinforcing steel make reinforced concrete systems both economical and practical, especially in remote or logistically challenging areas. With the rapid growth of urban populations in both developing and developed countries, reinforced concrete has become the preferred material for residential construction. However, the lack of design and application expertise in many regions makes proper reinforcement placement and detailing even more critical (Wight, 2016).

3.2 Wooden Systems

Conventional timber building systems are categorized into masonry (log masonry) and frame systems (Çakır, 2000 as cited in Yıldırım, 2010). In modern practice, they are classified as log, frame (post and beam), and panel systems, with additional structures using layered wooden elements for spanning large openings (Götz et al., 1989, as cited in Yıldırım, 2010).

Log masonry systems, requiring large amounts of timber and exhibiting poor earthquake resistance compared to frame systems, have seen limited use. In contrast, timber frame systems, characterized by smaller load-bearing sections, ease of transportation, and flexible architectural solutions, became more widespread. Conventional timber frames often used regional infills like stone, brick, adobe, or wood. However, heavy stone infills increased seismic vulnerability, while timber infills enhanced strength and rigidity during earthquakes, especially when reinforced with slats to support plaster (Acar et al., 2004, as cited in Eren, 2015).

In traditional timber construction, wall studs were left exposed, and lateral stability was achieved through corner braces. In more advanced timber systems, cladding elements took over this role, boosting rigidity (Eren, 2015). The development of these advanced systems in the 19th century was driven by steam-powered routers and machine-made nails, which allowed for more efficient joints, faster construction, and standardized components (Eren, 2015)

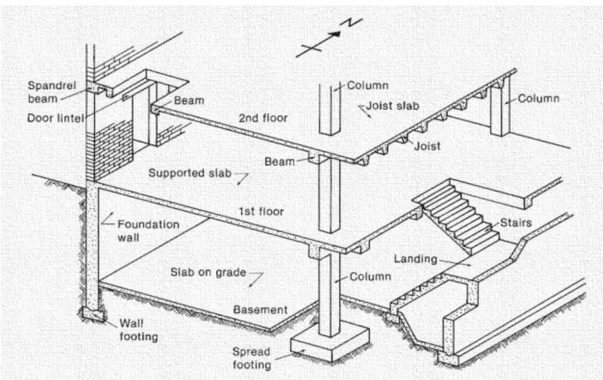

Fig. 1. Reinforced Concrete System (Wight, 2016)

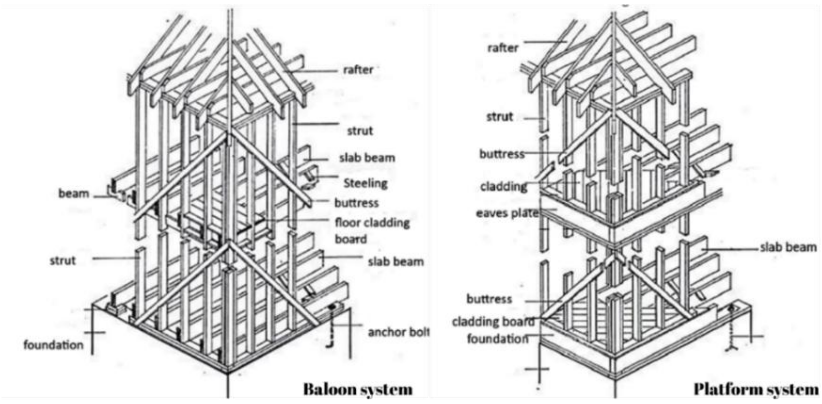

Fig. 2. Platform System and Baloon System (Eren, 2015)

In frame systems, wall and floor elements are assembled on site. These systems are classified as either single base or double base, depending on how they connect to the foundation (Çakır, 2000, as cited in Yıldırım, 2010). In platform frame systems, one story wall panels are prefabricated for each floor using a standard method. Timber studs are evenly spaced and covered, forming strong, continuous load-bearing walls. This approach boosts both strength and construction speed (Çakır, 2000; Avlar, 2002; Chiuini & Underwood, 2007; Götz et al., 1989, as cited in Yıldırım, 2010).

Balloon frame systems, an early form of the advanced timber system, feature slender, closely spaced uprights running continuously from foundation to roof. Although initially praised for their lightweight nature, balloon frames declined due to fire risks and construction challenges associated with lengthy uprights (Eren, 2015). Fig. 2 illustrates the schematics of the balloon and platform systems.

Both conventional and modern systems require metal fasteners for joint integrity. Conventional joints suffered from strength loss due to material removal at connections, whereas today, adhesives and threaded plates, albeit limited to factory conditions, improve joint performance. Nevertheless, simple mechanical fixings generally suffice in timber construction (Eren, 2015).

3.3 Structural Steel Systems

The use of metal materials as load bearing elements became widespread in the first half of the 19th century; in the previous period, metals primarily served as connection components. The Severn Bridge, completed in England in the late 18th century, is recognized as the first structure made entirely of metal. While steel was initially preferred for commercial buildings, it soon found widespread use in housing as well. This shift was largely due to its ability to span long distances, offer slender and durable sections, remain lightweight, and allow for efficient heat conduction. Additionally, since steel components were produced in factories and assembled on-site, construction times were significantly reduced. Thanks to dry assembly, construction was unaffected by weather conditions, and the need for site space was minimized. After the completion of the structure, steel frames could also be adapted to new functions, thus extending the service life of the building (Eren, 2015). The connection technology of steel structures also evolved over time. Riveting was widely used in the 1920s and was displaced by bolting in the 1930s. In the 1950s, welding in workshops became established, followed by on-site welding in the 1970s. In the 1990s, controlled on-site welding and other systems of connection began to appear. Most common types of connections today are bolted connections, which are friction-dependent, bolt shear and bearing, and welded connections, which consist of full or partial penetration grooves and fillet welds (Design and Construction of Structural Steel Work, 2021). Steel construction eliminates the need for formwork and scaffolding, allowing for smaller foundations. It can be reused even on weak ground, offers greater flexibility in architectural design, and enhances the visual appeal of buildings. Its lightweight nature makes it suitable for high-rise structures, while its earthquake resistance ensures safety in seismic regions. In addition, steel speeds up the construction process, facilitates on-site inspections, and allows for later transportation and modifications. Being 100% recyclable, it also supports sustainability, and it can be used to strengthen structures when necessary (Türk Yapısal Çelik Derneği, 2020).

4. Lightweight Steel Construction

Two types of structural systems are used in steel structures: one is the widely preferred system consisting of hot-rolled heavy steel structural members, and the other is the light steel structural system consisting of cold-formed thin-walled steel profiles, which is increasingly being used. The definition of "light" is related to the thinner cross-sections of the elements and components used in the construction. Light steel structures are completely different from steel frame structures in terms of the profiles used and structural system features (Ozcan, 2005).

Stainless steel cold formed sections are commonly used for structural components where the focus is on material efficiency rather than high strength. This construction method is cost effective, offering a high production potential with minimal investment in manufacturing technology. Cold formed sections are created from flat sheets, typically using two main techniques: press braking and roll forming. Press braking works best for simple shapes and smaller quantities, making it ideal for prototyping. Roll forming, on the other hand, is perfect for producing larger quantities and more intricate shapes. As illustrated in Fig. 3, the roll forming machine is used in the production process, and Fig. 4 presents the most common section profiles.

The light steel system is a construction method where structural elements, such as wall panels, roof panels, and floor beams, are pre-fabricated in factories and then assembled on site. The elements of the light steel system work both independently and in combination with supporting components to form a complete structural system. Due to its durability and fast installation process, the light steel system is a preferred choice for projects requiring efficiency, strength, and quick turnaround times (Ozcan, 2005).

Steel consists of 0.16–0.20% carbon and the remainder is iron; as the carbon content increases, hardness also increases. It also contains nitrogen, phosphorus, silicon, copper, and manganese; with the addition of nickel, chromium, molybdenum, and vanadium, high-quality alloys are obtained. Compared to structural steel, light steel has lower carbon content and strength because it is produced from softer alloys suitable for cold forming; its profiles and sheet thicknesses are thinner. Therefore, in the light steel system, all walls are load-bearing (Özcan, 2005). The light steel system is similar to the timber construction system consisting of load-bearing walls; horizontal floor and roof beams, along with vertical interior and exterior walls, carry all the loads of the building. Galvanized thin-walled profiles are reinforced to withstand both horizontal and vertical loads. Connection elements, cross bracing, and sheathing panels provide additional rigidity to the structure (Yıldırım, 2010). Standard-section light steel panels are designed to match the dimensions of 5 cm thick structural timber (Eren, 2015). Because of their limited spanning capacity, light steel elements are generally more suitable for residential and low-rise buildings. Their easy manufacturing, transportation, rapid assembly, and low dead loads make them particularly advantageous for smaller projects. On the other hand, conventional heavy steel systems, which are perfect for large spans and high rise structures, are not cost effective for smaller buildings and demand more complex organization and skilled labor (Ekinci, 2006).

4.1 History of Light Steel Systems

Cold formed steel structural members have been used for over a century, with their application expanding significantly in the last few decades. These members are highly versatile, allowing for optimization in size and design. This flexibility brings both theoretical and practical design challenges, but also offers innovative solutions. The growing use of cold formed steel is driven by improved understanding of its behavior, the availability of design standards and suitable materials, and the increasing demands of the construction industry (Baehre et al., 1982).

Initially used in interior partition systems and as roof supporting beams (purlins) due to their light weight, cold-formed steel profiles gradually became widespread in simple building and roof systems in industrial structures and recreational facilities. The first technical studies on cold-formed steel began in the 1930s in the United States, and the first standards prepared by AISI were developed by 1946. In the post-World War II periodesearch on light steel structures expanded, particularly in Japan, Germany, and Scandinavian countries, with the first use of this technology occurring in Germany by the late 1950s. In the 1980s, the light steel frame system reached its current form. During the same period in the United States, with the increasing demand for wood and rising costs, light steel houses began to replace conventional timber frame structures thanks to advantages such as portability and 100% recyclability of light steel. Today, approximately 20% of single and multi-story buildings in the United States are constructed with light steel frame systems. While these developments also continued outside the United States, especially in Australia and Canada, the sector did not develop at the same rate in Europe due to the existing building stock being largely completed and the relatively lower housing demand. Today, the light steel industry has reached its most advanced level in the United States (Mimarlar Odası İzmir Şube, 2006).

With the development of production techniques that made the use of cold formed steel profiles possible in the construction sector, this material also started to find a place in building construction. With the introduction of light steel into the sector, the use of cold formed panels became widespread in building components such as roof coverings and floor reinforcements. In addition, both cold formed and pressed profiles were developed for curtain wall cladding, beam systems, and formwork elements. The first applications of these materials were seen in simple, fire resistant film studio buildings constructed in the United States and the United Kingdom. During this period, the Lowell House designed by Richard Neutra attracted attention by being completed in a very short time based on the principles of the light steel system; this prefabricated light steel building, introduced at an exhibition in Chicago in 1933, stood out for its similarity to the timber platform frame system. Following these developments, the light steel system became a common construction method in the United States in the pre-World War II period (Eren, 2015).

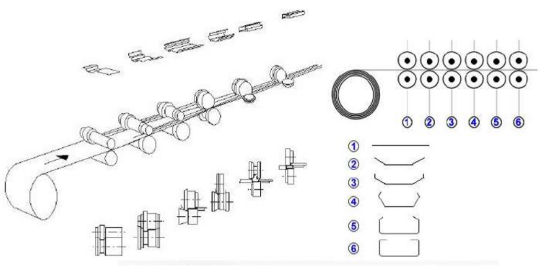

Fig. 3. Roll Form Machine (Mendes, 2019)

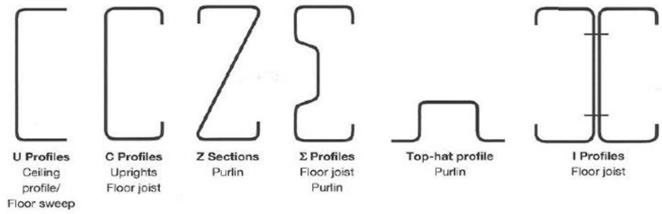

Fig. 4. Most Common Section Profiles (Mendes, 2019)

4.2 System Design

In light steel building systems, the plan geometry is of great importance in terms of the behavior of the load bearing system. The most suitable plan types are square or rectangular plans where the load bearing walls are placed at right angles. This arrangement simplifies the connections and increases the stability of the structure.

Sloped or curved plans can also be applied according to architectural requirements; however, in such arrangements, connection points and load-bearing behavior must be carefully addressed.

According to the AISI (1995) standard, the spacing of steel studs in load bearing walls should not exceed 60 cm, and floor joists should be aligned on the same axis as the wall studs. Especially in cases where joists are placed at an angle to the wall plane, the spacing should be tightened. In corner joints that are not at right angles, structural continuity should be ensured by using special profiles (Yıldırım, 2010). In walls with curved plans, the header profiles are bent according to the curved form. Flexible, standard compliant elements such as "Contour track" or "Flex-C track" have been developed to reduce buckling that may occur during this process. However, if the cladding material does not adapt to the curvature, loss of rigidity and visual distortions may occur. Therefore, for curved walls, a minimum radius of 12 meters and a maximum stud spacing of 3 meters are recommended. OSB, gypsum board, and laminated wood can be used for cladding (Yıldırım, 2010).

In light steel structures, facade design is a critical component not only in terms of aesthetics but also in terms of load bearing capacity. Since facade walls serve as load bearing elements in these systems, the placement, size, geometry, and cladding details of openings directly affect the structural performance. While the load bearing system determines the facade design, elements such as the possibility of leaving openings, their dimensions and forms, and the texture of the cladding material are considered as fundamental design criteria. Openings in walls can be arranged according to architectural requirements; in such cases, the stud spacing can be narrowed depending on the system module. However, since walls in light steel systems serve as load bearing elements, such interven-

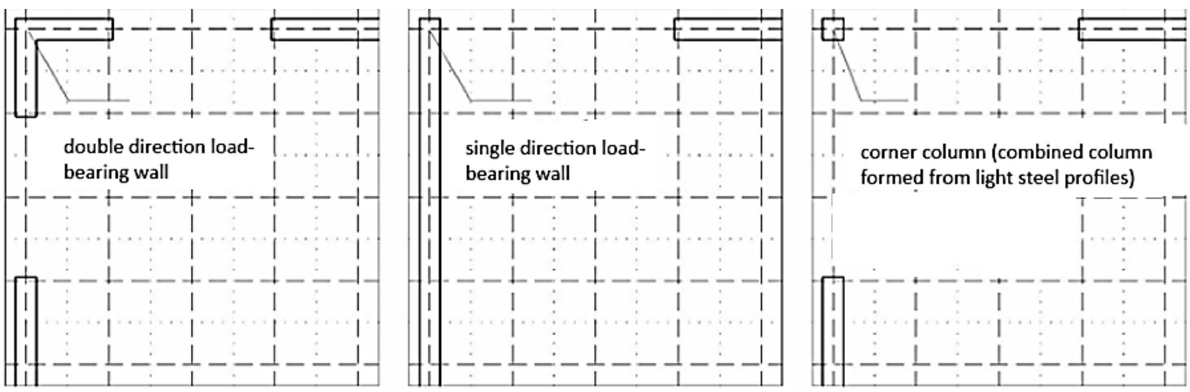

Fig. 5. Examples Of Load-Bearing Walls On Facade (Yıldırım, 2010).

tions must be planned in a way that does not affect the load bearing capacity. Since the profiles are usually placed behind the cladding, the structural system remains hidden from the outside, giving the facade a mostly solid appearance. Similar to masonry buildings, large wall openings can weaken the structure, so light steel systems also tend to feature wide surfaces with smaller openings. However, instead of using load-bearing facade walls, it is also possible to use rigid light steel frames that carry loads through moment transfer. In these systems, the frame itself provides rigidity without relying on diagonal bracing or cladding panels. In cases that require greater stiffness, the studs can be designed as box (composite) sections. When diagonal bracing is used, wall openings are not possible in those areas, so the placement of bracing elements must be planned with both structural stability and facade design in mind Yıldırım, 2010).

Corner points are among the most critical areas in terms of structural rigidity. Therefore, the principles of light steel systems do not recommend creating openings at corner points. Just like in masonry systems, these regions, where load bearing walls support each other, provide resistance especially against horizontal loads. If an opening must be created at a corner, the load-bearing capacity should be ensured by a moment resisting steel frame, and the studs at the connection points should be designed as composite sections and columns. As shown in Fig. 5, various design methods for corner windows in light steel structures are presented.

The shape and orientation of openings on the facade also affect the structural behavior. In particular, openings that extend horizontally with limited height reduce the resistance of load bearing walls against horizontal loads. This is because such openings interrupt the transfer of diagonal loads and weaken the walls' ability to carry shear forces. As a result, buckling and shear effects may occur in the studs near the openings (Yıldırım, 2010).

4.3 Materials Used in Lightweight Steel Structural Systems

The materials used in light steel structural systems both enhance structural strength and meet performance criteria such as thermal and acoustic insulation. In these systems, structural sheathing materials can be used as alternatives to horizontal and diagonal bracing; however, this choice must be considered during the early stages of design. Materials such as Oriented Strand Board (OSB) and plywood stand out for structural sheathing purposes. It is recommended that OSB Class 3 panels have a minimum thickness of 11 mm, and plywood panels at least 12 mm; during installation, self-drilling screws should be used at intervals of no more than 20 cm along the edges and 30 cm in the middle areas. According to findings from the NAHB Research Center, materials like OSB, plywood, or gypsum board provide more effective support for the buckling resistance of steel studs compared to bracing methods. Reducing the screw spacing creates more contact points on the steel profiles, thereby increasing this resistance; moreover, sheathing panels with a 2:1 aspect ratio contribute higher strength compared to those with a 4:1 ratio. However, as the screw spacing decreases, the impact of this ratio difference on structural strength diminishes.

According to North American standards, the thicknesses of OSB panels used in light steel structures vary depending on their area of application. For structural sheathing in load bearing walls, a minimum thickness of 9 mm is recommended; for floor substrates, 18 mm; for bottom sheathing of roof trusses, again a minimum of 9 mm; and for flat roofs or attic spaces, panels with a thickness of 18 mm are advised (Akay, 2013). OSB and gypsum boards, which are widely used in light steel systems, have a broad range of applications from exterior facades to roof surfaces and floor coverings. OSB is a moisture-resistant, high strength panel that has become a widely used alternative to plywood around the world (Yıldırım, 2010). It is not only suitable for exterior facades but also works well on interior walls where heavy furniture or decorative elements need to be mounted (Mendes, 2019). OSB panels are made by pressing wood strands, each about 10 cm long, into layers with each layer oriented perpendicular to the one below. In light steel structural systems, they are especially valued for sheathing and providing rigidity. Their light weight, ease of transport and cutting, and ability to be screwed into easily make them highly practical during construction.

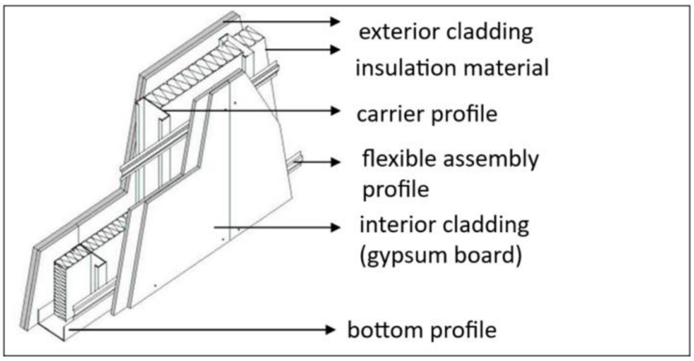

Fig. 6. Light Steel Wall Section (Ekinci, 2006)

Designed to withstand harsh weather conditions, these panels simplify exterior facade applications and are capable of carrying heavy loads such as furniture and decorative objects. In addition to providing structural strength, they also offer thermal insulation, making them a versatile material. Thanks to their high performance in horizontal applications, they help distribute stresses evenly within structures, thereby increasing stability. Shear tests have shown that OSB panels significantly enhance the ductility and stability of wall systems.

According to the EN 300 standard, OSB panels are divided into four classes based on their usage conditions and mechanical properties: OSB/1 panels are used for general purpose interior decoration and furniture in dry environments, while OSB/2 panels are suitable for structural use in dry environments. OSB/3 panels are recommended for structural use in humid environments, and OSB/4 panels are preferred for applications requiring high structural performance in humid conditions. Today, OSB/3 class panels are widely used in light steel systems due to their superior performance against weather conditions during the construction process (Mendes, 2019).

Another wood based material, cross laminated timber (CLT), was developed in Germany by Friedrich Otto Hetzer in the 20th century. This material is produced by gluing together layers of wooden lamellae arranged in crosswise directions, preserving the natural properties of the wood while eliminating internal defects. Due to its layered structure, stress is distributed more evenly across the surface instead of concentrating at specific points, giving the material a more homogeneous load-bearing capacity.

Another material is composite panels, which are produced by combining wood particles with Portland cement and shaping them through pressing. These panels combine the flexibility of wood with the durability of cement, and are used in both interior and exterior cladding applications, offering high resistance to impacts, fire, sound, moisture, and fungal attacks. However, they also have disadvantages such as high cost, heavy weight, and the need for wider metal profiles during installation. Moreover, due to their rigid structure, they can be prone to cracking (Mendes, 2019).

Non-structural cladding materials are also widely used in light steel systems. This group includes non-standard OSB panels, as well as gypsum boards, which are particularly preferred for interior cladding and decorative finishing layers. Gypsum boards are produced by placing a gypsum-based mixture between two layers of paper, and depending on the additives used, they can be applied in different environmental conditions. Commonly used for interior walls and ceiling applications, these panels can be mounted directly onto the steel frame or on top of OSB panels; their joints are sealed with tape to prepare the surface for paint or ceramic finishes. Isolpro panels, produced from a mixture of lightweight concrete and polystyrene, provide thermal and acoustic insulation and can be adapted for a variety of surface applications on interior and exterior walls, floors, and façades.

In Turkey, gypsum boards are commonly applied on the interior surfaces of external walls, on both faces of internal partition walls, and on ceilings. Insulation materials such as glass wool or rock wool are placed behind these boards to provide both thermal and acoustic insulation. Manufactured in compliance with the TS EN 520 standard by companies such as Knauf, Lafarge-Dalsan, and ABS, these products include the ALB type, white in color, used for interior spaces, and the moisture-resistant ALY type, green in color, used in wet areas and exterior applications. For curved surfaces, 6 mm thick boards are shaped with water before installation. Both OSB panels and gypsum boards can be used for structural sheathing purposes; however, OSB panels offer a higher degree of stability (Akay, 2013). The typical configuration of a light steel wall section is illustrated in Fig. 6.

Another fundamental material used in light steel structures is mineral stone wool. Since steel does not naturally provide thermal insulation, this deficiency is compensated by filling materials. In the panels, profiles are placed at 60 cm intervals with a maximum thickness of 1.5 mm, limiting the formation of thermal bridges to only the areas where steel is directly present. The surface area ratio of these thermal bridges is a maximum of 0.375%, while all remaining areas are insulated with stone wool. In addition to this insulation, polystyrene-based cladding is commonly applied on facades to ensure waterproofing and eliminate thermal bridges. Due to the low thermal mass in light steel systems, HVAC systems become effective in a short time, allowing the indoor climate to be rapidly adjusted without waiting for walls to heat up or cool down. This results in lower energy consumption compared to conventional buildings.

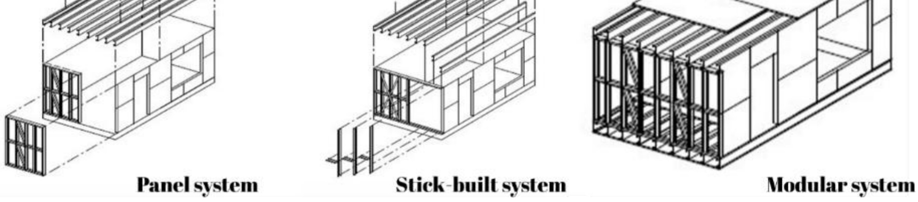

Fig. 7. Panel System, Stick Built System, Modular System (Mendes, 2019)

Fig. 8. Modular Construction (Lawson et al., 2008)

Moreover, stone wool significantly contributes to sound insulation. The use of high-density materials together with low density layers enhances acoustic performance; thanks to the multilayered panel structure, while OSB and gypsum board applications provide structural support, stone wool plays a key role in resonance reduction and sound damping. This combination provides sound insulation up to three times better than conventional construction methods (Mendes, 2019).

4.4 Lightweight Steel System Construction Techniques

The light steel system has attracted the attention of many organizations worldwide and has become an increasingly widespread construction method thanks to its ease of production, clean site conditions enabling fast assembly, waste-free structure, and cost advantages that can compete with reinforced concrete. In light steel residential construction, three primary assembly methods are employed: the bar (stick-built) system, the panel system, and the modular system, as illustrated in Fig. 7.

Among these systems, the panel construction method stands out as the most widely adopted technique. Profiles are manufactured in factory settings according to project-specific dimensions and transported to the construction site as wall, roof, and floor panels. These panels are then assembled on a pre-prepared foundation. The lightweight nature of the panels significantly eases the transportation and installation processes (Eğitmen, 2013). Compared to the bar (stick) system, the panel system offers a fourfold faster assembly process (Özcan, 2005). Furthermore, it enables uninterrupted work regardless of weather conditions, thereby ensuring the timely completion of projects, and eliminates deformation risks such as shrinkage, swelling, and warping commonly encountered in conventional materials like wood. The integration of door and window openings during the panel production stage further reduces on-site assembly time. Factory-based production enhances quality control and dimensional accuracy while minimizing the need for site labor and promoting greater automation opportunities. In addition, compared to on-site production, it offers a fivefold safer working environment, providing significant advantages in terms of occupational health and safety. Panels manufactured in controlled factory environments deliver high geometric precision and reliability (Grubb et al., n.d.).

Another method employed in the production of light steel structures is the stick-built system. In this construction technique, profiles prepared to the full story height are transported to the construction site, and the assembly operations are carried out directly on-site. Compared to modular and panel systems, this method generally results in a longer construction period. Moreover, if the galvanization on the profiles is damaged during transport or processing, the affected areas must be recoated with anti-corrosion paint (Eğitmen, 2013). In this method, panels are assembled piece by piece on-site, and then surface cladding and other components like insulation are added. The profiles come with pre-punched holes, which makes installation easier. The stick-built system also offers flexibility, as changes can be made during construction. Unlike modular systems, it does not require manufacturers to invest in a dedicated factory, which significantly reduces initial costs (Yandzio et al., 2015). Another construction method is the modular building system. According to Terim (2006), this system was promoted globally by the United Kingdom and several major companies. To enhance fire resistance, special thermal insulation solutions have been developed specifically for modular elements. Moreover, by using additional connection components, it is possible to construct buildings up to six stories high within this system (Mimarlar Odası İzmir Şubesi, 2006). The modular units are transported by crane and stacked on top of each other, with the entire system stabilized through steel cables or tensioning elements. This method stands out due to its rapid assembly within 2–3 days and the transportable and reusable design of its modules (Eğitmen, 2013). In this construction method, units are completed in the factory and then transported to the site for horizontal and vertical assembly (Yandzio et al., 2015). Especially in large-scale productions, it is considered the most cost-effective system because fixed costs such as prototyping and assembly, which are independent of scale, can be spread across many units. Additionally, conducting production off-site provides a significant advantage in terms of occupational health and safety, as it is five times safer compared to on-site construction. The world's largest structure built with the modular system, consisting of approximately 1,400 modules, is located in Manchester, and its visual representation is provided in Fig. 8 (Lawson et al., 2008).

The elements used in the assembly of light steel structural systems are important in terms of strength, economy, and production speed. Assembly elements and methods can be classified as fasteners such as screws and bolts, spot welds and rivets, and anchorage elements. Screws and bolts are removable fastening tools, whereas spot welding, riveting, and welding processes are non-removable fastening methods. Anchorage operations are generally performed by fixing light steel structural profiles to reinforced concrete foundations.

Welded joints are not typically used in light steel systems since they ruin galvanized coatings and quality cannot be guaranteed under site conditions. Heavy equipment requirements and extended application time also make welding less convenient. In addition, replacement and dismantling are not practical with welded joints. Spot welding is also not ideal since it ruins the galvanized surface and reusability is not practical. Alternatively, bolted connections are also commonly used. They offer efficient assembly of light steel elements with reinforced concrete or other steel elements. In light steel systems, bolted connections are commonly used to join light steel elements to reinforced concrete or other steel components (Yıldırım, 2010). When connecting steel profiles to OSB panels, the screw heads should have a minimum diameter of 7mm and must be countersunk into the OSB to prevent any protrusions that could affect the surface finish. Since OSB panels serve a structural function, screws should be placed at least 9mm from the panel edges. Additionally, the spacing between screws should be carefully calculated to ensure the stability of shear walls under horizontal loads (Mendes, 2019).

5. Lightweight Steel System Practices in Selected Regions

In Europe, cold-formed profiles have primarily been used as purlins or beams since the 1950s, and were later incorporated into various structural applications such as columns, wall studs, primary load-bearing elements, and roof trusses. The fact that cold-formed steel became more economical compared to timber and hot-rolled steel accelerated this trend (Baehre, 1982). During the 1970s, the use of high-yield-strength steels and deep sections became widespread to enhance load-bearing capacity, while longitudinal and transverse profile shaping techniques were developed. In the same period, the "stress skin" design, where the surface bears horizontal loads, also provided economic advantages. In Western Europe, especially in the United Kingdom and Scandinavian countries, Cold-Formed Steel (CFS) is frequently employed in multi-storey residential buildings. In these structures, CFS panels reinforced with OSB are applied in combination with dry materials or lightweight concrete. Within the EU, manufacturers are heavily investing in R&D activities focused on CFS solutions for multi-storey structures. It is noted that the Spanish company Teccon Evolution has obtained a European Technical Approval for this system. A study conducted in the United Kingdom found that the Metsec SFS system was 39% more cost-effective than conventional block walls, offering additional advantages such as reduced labor costs, environmental benefits, and quicker project completion (Nagy & Dubina, 2011).

In the North American residential market, light steel structures account for 20% of the share. They are commonly used in the construction of single or two storey villa type homes, especially in earthquake-prone areas like California, where cold-formed C-section steel profiles are typically employed. Rising timber prices and the growth of the supporting industry have made steel-framed housing an economically viable alternative (Wang et al., 2014).

Cold-formed steel elements are produced using C and Z section profiles and are typically applied in the form of either attached or detached structures. Due to inadequate sound insulation, their use in multi-storey buildings remains limited. Two main methods are employed to resist lateral loads and seismic effects: the first involves light steel shear walls formed with gypsum boards and galvanized steel sheets, and the second utilizes diagonal steel bracing elements. Vertical loads are carried by the light steel structure, while horizontal loads are resisted by conventional steel bracing. Additionally, placing glass wool within the wall studs and floor joists effectively interrupts thermal bridges, thereby providing thermal insulation (Wang et al., 2014).

CFS systems are also used in multi-storey buildings through structural shear wall panels, load-bearing wall panels, and floor/roof panels. In Canada, Bayley Metal Products constructed the six-story Kingsway Arms

Retirement Home, 9,890 m², with this system. Steelform developed a unique solution named the "Mega Joist" to provide additional structural support for the wall beams and intermediate floors. Moreover, in 2007, the American Iron and Steel Institute (AISI) published the first seismic design standard specifically for CFS structures (Nagy & Dubina, 2011).

Japan has shown significant interest in light steel structures due to its high seismic risk. Structures known as "Sheet Steel Housing" are constructed using box-shaped steel panels and floor systems. Steel sheets with a thickness of 1.0 mm are utilized, and both surfaces are covered with gypsum boards to provide durability, stability, thermal, and acoustic insulation. The use of timber has been limited due to its combustibility and the long reconstruction time required after disasters, while the preference for steel has also increased as part of efforts to preserve forests. In 2000, 70% of residential buildings in Japan were made of steel, 19% of wood, and 11% of reinforced concrete. The production of cold-formed steel has risen since the 1950s, and by 1980, 70% of these products were being used in the construction sector (Nagy & Dubina, 2011). Following the 1995 Hanshin earthquake, approximately 50,000 temporary housing units were constructed, of which around 3,000 featured steel frames. In the same year, the Japanese Ministry of Construction published performance standards for steel-framed houses. In 1996, steel manufacturers initiated studies focusing on structural performance and insulation. By 2005, approximately 20,000 steel-framed houses had been constructed (Nagy & Dubina, 2011). The KC (Kozai Club) light steel construction system, introduced in 2000, was officially recognized with the publication of new regulations in 2001 and gained widespread acceptance in the market (Kawakami, 2008). In this system, fire, thermal, and sound insulation are provided by applying thermal insulation and ventilation layers on the exterior surfaces and gypsum board on the interior surfaces. In KC-type structures, wood based cladding materials are generally preferred; in three-story buildings, the ground floor is constructed with reinforced concrete, while the upper floors are built using a steel framing system. This type of structure provides 60 minutes of fire resistance. To achieve higher fire and seismic performance, Nippon Steel developed the "Nittetsu Super Frame" (NSF) system. Seismic safety is addressed in two stages: during moderate earthquakes, the focus is on maintaining structural rigidity, while during more severe seismic events, the ability to dissipate energy becomes crucial. When wood cladding is not sufficient, new ceramic-based panels with high rigidity and energy dissipation capacity have been introduced. In the NSF system, floors are built using the platform framing method, and interstory deformation is prevented by high-rigidity connectors. The system received official structural performance approvals in 2005 and 2007. Moreover, in line with ISO 834 standards, fire insulation for cladding elements is achieved through the "membrane method," which protects against fire temperatures up to 945°C.

While light steel construction systems have reached usage rates of up to 20% in the housing sector in Western countries, this rate remains below 1% in Türkiye. This situation reveals that industry stakeholders in Türkiye have not shown sufficient interest in light steel systems (Türk Yapısal Çelik Derneği, 2020). In Turkey, light steel systems are generally applied as panel systems, and these systems are referred to as prefabricated structures. Around 80–90% of prefabricated construction companies utilize this system (İMO Eskişehir Şubesi, 2020, as cited in Fenli & Ünal, 2023). In addition, the on-site cladding system, in which panels are assembled directly at the construction site, is also widely preferred (Seçkin, 2022, as cited in Fenli & Ünal, 2023). In terms of design, the TS 11372 standard was followed until 2014. After this date, within the scope of harmonization with the European Union, the TS EN 1993-1-3 Eurocode 3 standard was adopted. Furthermore, the Turkish Building Earthquake Code, which came into force in 2019, includes a dedicated section for light steel structures and sets out the rules for sizing structural system elements. The regulation specifies that horizontal load-bearing systems must be designed either as "sheathing panel systems" or as "braced panel systems" (Fenli & Ünal, 2023). Fig. 9 illustrates the construction requirements for light steel structural systems as specified in the Turkish Building Earthquake Code. In practice, the production of steel structures consists of three main stages: the production of steel panels, the assembly of the load-bearing system, and cladding with OSB panels. All production and assembly processes are carried out in accordance with the project specifications, and the structure is anchored to the reinforced concrete foundation using steel anchors (Taşkıran, 2005, as cited in Fenli & Ünal, 2023).

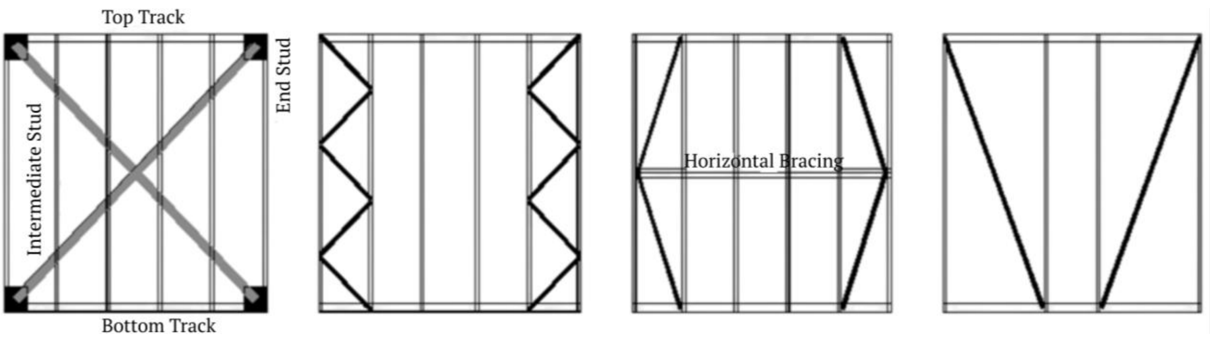

Fig. 9. Turkish Building Earthquake Code Light Steel Framing System (Çevre ve Şehircilik Bakanlığı, 2018)

6. Universal Design Codes

The development of standards for stainless steel structural design began with the American Iron and Steel Institute (AISI), which published the first specific standard in 1968 based on research conducted at Cornell University. This standard underwent revisions in 1974 and was later superseded by an American Society of Civil Engineers (ASCE) standard in 1991. In Europe, the Guide to the Design of Stainless Steel Structures, published by Euro Inox in 1994, was incorporated into Eurocode 3 in 1996. Japan and South Africa introduced their own standards in 1995 and 1997, respectively, while Australia and New Zealand followed with a standard in 2001. These initiatives established the global framework for stainless steel structural design (Gardner, 2005).

In Turkey, the regulation titled TS 11372, "Steel Structures - Lightweight - Formed with Cold-Formed Profiles - Rules of Calculation" came into force on April 28, 1994. This standard outlines calculation rules based on elastic theory for sizing thin-walled elements produced by cold-forming structural steel plates, intended for use as load-bearing elements not subjected to significant impact loads. After 1999, the use of light gauge steel for permanent structures in Turkey became increasingly common. However, TS 11372 is not specifically tailored for light gauge steel; it applies more broadly to cold-formed steel elements within structures. The mention of "steels thicker than 4 mm" further emphasizes that the regulation was not designed with mild steel applications in mind (Öncü, 2010).

The AISI initiated early efforts for the use of cold-formed steel elements in construction as early as the 1930s. Recently, the CSA S136 standard developed by the Canadian Standards Association (CSA), widely used in Canada, was merged with AISI standards and is now implemented as the AISI - North American Standard (NAS). This unified standard is also referenced in countries lacking their own codes for light gauge steel structures (Öncü, 2010).

Eurocode 3, developed for the design of steel structures across Europe, dedicates its third part specifically to structures composed of cold-formed steel. Beyond Europe, Eurocode 3 is commonly used as a reference in African nations and parts of the Middle East. Furthermore, in Australia and New Zealand, where light steel construction is prevalent, a standard issued by the National Association of Steel-Framed Housing (NASH) is applied, and a joint-use agreement with Japan supports its implementation. Scandinavian countries are also actively conducting research and developing standards in the field of light gauge steel construction (Öncü, 2010).

6. Results and Discussion

CFS (Cold-Formed Steel) framed houses offer significant advantages in terms of environmental comfort and health. These houses maintain temperature balance with heating and cooling properties that enhance energy efficiency. Additionally, the steel used in CFS framing systems does not require additional protective chemicals and does not emit gases or volatile organic compounds, thereby improving indoor air quality. Steel is also resistant to mold and decay, which is an important factor for health. These structures offer healthier living conditions, energy efficiency, and sustainability.

The earthquake and fire resistance of CFS provides a major advantage, especially for regions with seismic and fire risks. Steel has the capacity to absorb energy and, with its flexibility, helps the structure sustain less damage during earthquakes. Light structures are less affected by earthquakes compared to conventional heavy structures, which increases the suitability of CFS for earthquake-prone regions. In steel frame systems, Framecad CFS profiles are securely connected with screws to form a robust structure. The long-term durability of these structures is based on the material quality and structural integrity.

The modular prefabrication method provides a significant advantage in accelerating construction processes and reducing labor costs. CFS enables the transportation of prefabricated components to the site, minimizing the need for labor and shortening construction time, thus making the construction process more efficient. Additionally, prefabrication improves construction quality and reduces site congestion and waste.
While the global adoption of CFS is significant in some regions, it remains limited in others. One of the main reasons for this is the lack of comparative analyses and comprehensive research on the performance of CFS framed building systems. However, the advantages offered by these systems hold substantial potential, especially in earthquake-prone areas. Steel structures provide a strong alternative to conventional methods, with their flexibility in architectural designs, recyclability, and sustainability.

7. Conclusion

This study has comprehensively examined the advantages of light steel frame systems compared to conventional construction methods in terms of sustainability, seismic performance, and economic efficiency. The prefabricated nature of these systems allows for faster construction processes and offers significant advantages, particularly in regions with high seismic risks. Moreover, the adoption of these systems is of great importance in meeting the rapid urban development requirements driven by increasing urbanization demands.

The global use of light steel systems is widespread in some regions while limited in others. One of the strongest aspects of these systems is their earthquake resistance, which is crucial in seismically active areas. Additionally, their flexibility in architectural design, recyclability, and low carbon emissions contribute to sustainability, making them an attractive alternative to conventional construction methods.

However, a major barrier to the widespread adoption of light steel frame systems is the lack of sufficient comparative analyses and the need for more comprehensive research on the global dissemination and performance of these systems. This study highlights the importance of addressing this knowledge gap and emphasizes the need for further research to promote the broader adoption of these systems. Looking ahead, it is expected that light steel frame systems will gain wider acceptance. Real-world applications and comprehensive studies will further demonstrate the benefits of these systems, and they will become a critical component in the urbanization process by offering sustainable, efficient, and resilient construction solutions.

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Urban identity and architectural representation: A studio practice

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Abstract. Urban identity is the sum of elements that define the character and uniqueness of a city. In this context, exploring the architectural representation of urban identity elements in a historically and culturally rich city like Istanbul holds significant importance. This study was conducted within the framework of the Architectural Representation studio, part of the Master's Program in Architecture at Yeditepe University, involving six students. The study consisted of three stages: the selection of identity elements, research and analysis, and scenario development. In the first stage, students were asked to select one of Istanbul's urban identity elements. This phase helped students understand the city's historical and cultural dynamics. In the second stage, the reasons why the selected element constitutes an identity component for Istanbul were researched and documented in written form. During this process, students had the opportunity to engage in critical thinking by questioning the architectural reflections of urban identity. In the third stage, students created a scenario based on their selected urban identity element and produced a media form to provide a visual representation of this scenario. This exercise aimed to enhance students' creativity and technical skills. As a result of the study, a total of six architectural representations of different urban identity elements in Istanbul were produced. The project offered students an opportunity to deeply understand the concept of urban identity while contributing to their comprehension of Istanbul's architectural and cultural layers. Furthermore, it introduces an innovative perspective to the literature by emphasizing the importance of architectural representation of urban identity elements. The findings serve as a valuable reference point for architectural education and urban design practices.

Keywords: Urban identity; Architectural representation; Creativity; Architecture education

1. Introduction

Urban identity encompasses the distinctive physical, cultural, historical, and symbolic attributes that collectively define the character of a city. It is not a static entity but a dynamic and evolving construct shaped by both tangible forms such as buildings, streetscapes, and monuments and intangible elements including memory, tradition, and social practices (Rapoport, 2005; Sepe, 2013). As cities continue to be reshaped by globalization, migration, and technological change, preserving and interpreting local identity has become an increasingly urgent concern in architectural discourse and practice (Alawadi, 2017; Erkip, 2000). Architecture plays a central role in articulating and reinforcing urban identity. Built environments do not merely serve functional needs; they act as symbols and carriers of meaning, reflecting societal values and historical narratives (Smaniotto Costa, 2008; Vale, 2008). Architectural representation is a key medium through which these meanings are explored, critiqued, and communicated. Representation thus becomes both a design tool and a cultural lens, offering ways to visualize and reimagine how identity is embedded in space (Corner, 1999; Kolarevic, 2013).

Architectural representation plays a critical role in both design thinking and education, functioning not merely as a means of visual communication but as a cognitive and exploratory tool. It enables students to externalize abstract concepts, test spatial ideas, and critically engage with cultural, historical, and social contexts (Evans, 1997; Corner, 1999). In educational settings, representational techniques ranging from traditional drawing and model-making to digital media and narrative-based outputs encourage iterative thinking and reflective learning. These methods foster students' ability to synthesize complex information, develop spatial literacy, and communicate design intentions with clarity and depth (Salama & Wilkinson, 2007; Ostwald & Williams, 2008). Moreover, when representation is positioned as an interpretive act rather than a purely descriptive one, it enhances students' critical thinking skills by prompting them to question how space, identity, and meaning are constructed and conveyed (Kolarevic, 2013). Thus, architectural representation not only supports technical skill development but also cultivates a deeper conceptual and contextual understanding—essential for shaping future architects as thoughtful and culturally aware practitioners.

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Within architectural education, studio-based learning provides an ideal environment for students to engage with such complex and layered topics. Studios encourage active, project-based exploration, integrating analytical thinking with creative production. Recent pedagogical studies emphasize the value of thematic studios that focus on real-world issues such as urban identity and cultural continuity as a means to develop students' contextual awareness and design sensibilities (Salama & Wilkinson, 2007; Ostwald & Williams, 2008). When these studios are situated in historically rich and culturally layered cities like Istanbul, they offer unique opportunities to engage directly with the urban environment. Istanbul, straddling Europe and Asia, is a palimpsest of civilizations and architectural epochs. From Byzantine and Ottoman heritage to modernist and contemporary interventions, the city's urban fabric embodies a diversity of identity markers. However, rapid urban transformation in recent decades has placed many of these elements at risk, making it essential to cultivate a deeper understanding of what constitutes Istanbul's identity and how it can be meaningfully represented (Bozdoğan, 2012; Kuban, 2010).

The aim of this study is to investigate how architectural representation can be used as a pedagogical method to explore and communicate urban identity, through a studio-based practice conducted with graduate architecture students in Istanbul. This paper presents a graduate-level studio project conducted within the Architectural Representation course at Yeditepe University, where six students were tasked with exploring the architectural representation of Istanbul's urban identity. The studio followed a three-phase process: identification of an urban identity element, critical research and documentation, and the creation of a narrative scenario expressed through a form of a media production. This process aimed not only to enhance students' representational and technical skills but also to foster a critical and reflective approach to the city's evolving identity. By framing urban identity as both a subject of investigation and a representational challenge, the study demonstrates how studio-based education can contribute to broader discussions in architectural theory and urban design. It highlights the potential of narrative-driven, research-informed design practices to foster critical engagement with the city and cultivate culturally responsive architectural thinking.

2. Materials and methods

This study adopts a qualitative, practice-based methodology embedded within a graduate-level architectural studio titled Architectural Representation, conducted at Yeditepe University. The participants consisted of six Master's students enrolled in the studio course during the academic term. The study was structured around a three-stage design process that aimed to deepen students' understanding of urban identity while enhancing their representational and critical thinking skills (Fig. 1).

Stage 1 – Selection of Urban Identity Element: In the first phase, each student selected a specific urban identity element associated with the city of Istanbul. These elements included culturally significant spaces, historical landmarks, architectural typologies, or symbolic public areas. The selection process encouraged students to reflect on the socio-cultural, historical, and spatial significance of their chosen elements and to articulate their relevance to the city's identity.

Stage 2 – Research and Analysis: Following the selection, students conducted individual research to explore the historical background, cultural meaning, and architectural implications of their chosen identity elements. This involved both textual analysis and visual documentation, including sketches, photographs, and conceptual diagrams. Students were also encouraged to consider how these elements have evolved over time and how they are currently perceived within the urban context. This stage was documented in short essays supported by visual material.

Stage 3 – Scenario Development and Representation: In the final phase, students developed a conceptual scenario based on their selected identity element. Each student created a storytelling frame or a short video as a medium of architectural representation, incorporating narrative structure, spatial interpretation, and symbolic visual language. This allowed for a creative synthesis of research, representation, and storytelling, enabling students to communicate their understanding of urban identity through an expressive and personalized format.

Throughout the process, desk critiques, group discussions, and peer reviews were used as part of the pedagogical strategy to encourage critical reflection and collaborative learning. The final outputs six representations in various mediums served both as representational products and as documentation of the students' interpretive journey. Data for this study were gathered through observation of the studio process, student reflections, and the analysis of the final visual submissions.

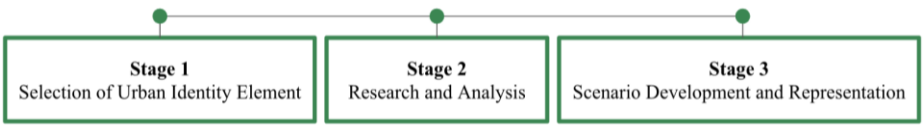


Fig. 1. Practice process stages

3. Results and discussion

The outcomes of the studio revealed that architectural representation served as an effective tool for exploring and communicating the multifaceted nature of urban identity. Each of the six student projects demonstrated a distinct interpretive approach, reflecting the individual's perception of Istanbul's layered urban fabric. (Table 1)

Table 1. Urban Identity Element and their features chosen by students

	Urban Identity Element	Location	Representation Title
Student 1	Mehmet Ayvalıtaş Square	Moda/Kadıköy	Gather Around
	Features: Almost unnoticeably, in the middle of the bustling streets of Moda, is a common park that eludes the harried attention of pedestrians. This little green area quietly defies expectations in the middle of the busy metropolitan landscape by hiding behind a façade of daily routine. Even though its architectural elements appear ordinary, they have a subtle appeal that only becomes apparent to those who take the time to observe its modest surroundings.		
Student 2	Maiden's Tower	Salacak/Üsküdar	Maiden's Myths
	Features: The myths to be explained are represented by the colors chosen around the Maiden's Tower. The Bosphorus line of the Maiden's Tower, a section of the Üsküdar coast-line and the Istanbul skyline are also reflected in the visuals of the work. Historical evidence shows that the tower was first mentioned in 410 BC. Although it has undergone various restorations since then, it continues to maintain the same value and iconicity.		
Student 3	Galata Tower	Bereketzade/Beyoğlu	Historical Journey of a Street Extending To Galata Tower
	Features: Galata Tower, which brings this street its significance, is located on the southern shore of the Historical Peninsula, separating the Karakoy and Beyoglu districts of the Bosphorus. Galata Tower, regarded as one of the oldest towers in the world, is one of the most significant structures that shapes the silhouette of Istanbul. Furthermore, due to its location at the end of Istiklal Avenue, recognized as one of the city's busiest, liveliest, and most important thoroughfares, and nestled among the historical narrow streets of the Galata and Beyoglu neighborhoods, the tower has consistently been a major attraction point from a tourist perspective. In this way, Galata Tower creates an atmosphere that provides both tourists and locals with the opportunity to experience Istanbul's rich cultural heritage up close.		
Student 4	July 15 Martyrs Bridge	Kuzguncuk/Üsküdar	From the Bosphorus Bridge to the 15 July Martyrs Bridge
	Features: The Bosphorus Bridge, now known as the 15 July Martyrs Bridge, is an important architectural structure that connects the historical and cultural fabric of Istanbul. This magnificent bridge, which was completed and put into service in 1973, is not only a transportation point by connecting the Asian and European continents, but also stands out with its architectural aesthetics and engineering success. The Bosphorus Bridge has a great symbolic value in the history of Istanbul. This bridge connected the European and Asian continents, changing the physical structure of the city and strengthening social ties. Contributing to the iconic silhouette of Istanbul, the bridge is more than just a means of transportation, it symbolizes the unified identity of the city. This structure, which encourages cultural interaction between people, has increased tourism and made the city a world-renowned center of attraction.		
Student 5	Kadiköy Ferry Pier	Caferağa/Kadıköy	Ferry Traffic
	Features: Kadıköy district has an important location in terms of country and city transportation. Some main transportation lines connecting various centers in Anatolia to Istanbul and various districts within the city pass through Kadıköy District. The biggest feature of this place is that it is crowded. A significant part of this crowd uses city line ferries. Therefore, the Ferry Pier and its surroundings in Kadıköy were considered as the area.Since representation is a method based on design knowledge in the mind, concepts related to the field have been determined. In other words, by determining the field, the concepts that this field creates in the mind are selected.		
Student 6	Altıyol Square	Söğütlüçeşme/Kadıköy	Altıyol Day/Night
	Features: Altıyol Square is recognized as one of the most iconic "public spaces" in the region, connecting the Metrobus, ferry terminals, and Bahariye Street. For many years, this square has served as a meeting point for people. Additionally, the bull statue located in the square contributes to the iconic status of the area. Considering all these features, it is essential to question the emotional impact that such a "public" space has on individuals. Despite being a meeting point and connecting important roads, the square falls far short of being an enjoyable area where one can spend time.		

As each student has chosen their own urban identity element they have also chosen the main features and specified their aims of creating their representations. Student 1 focused on the overlooked presence of an urban park, emphasizing its invisibility within the daily rhythm of city life. The aim was to draw attention to how this green space, despite its physical existence, often goes unnoticed and unrecognized. In the final representation in a form of a still storytelling frame, the student employed a combination of visual techniques to reinforce this concept: an overhead view highlighted the spatial context, while liquefaction effects distorted surrounding buildings to convey a sense of confinement and neglect. The use of red-painted human silhouettes in motion underscored the contrast between the park's passive anonymity and the city's active, unaware population, thus effectively portraying the tension between presence and perception in urban environments. (Table 2)

Student 2 explored the layered myths surrounding the Maiden's Tower, aiming to intertwine historical narratives with contemporary visual storytelling. The intent was to represent four prominent legends through a color-coded symbolic approach, integrating myth with spatial context. In the final visual work, the student utilized illustration techniques to depict the tower against a vivid pink sunset sky, embedding it within the modern Bosphorus setting, the Üsküdar coastline, and the current silhouette of Istanbul. Each color was carefully selected from naturally occurring tones in the scene to correspond with specific mythic elements, blending the factual and the legendary. This approach not only highlighted the cultural memory embedded in the tower but also demonstrated how representation can bridge historical continuity with present-day urban imagery. (Table 3)

Student 3 centered their study on Büyük Hendek Street and its evolving relationship with the Galata Tower, aiming to visually narrate the street's transformation from its historical roots to its current state. Through a sequential series of images, the work first emphasized the architectural shifts by illustrating stark structural changes over time. In later visuals, the focus transitioned from built form to everyday usage, capturing the ways in which people have interacted with and experienced the street across different periods. By combining architectural and social dimensions, the project effectively conveyed the layered temporal identity of the street, illustrating how urban space is continuously redefined through both physical change and lived experience. (Table 4)

Table 2. Student 1 representation aim and result

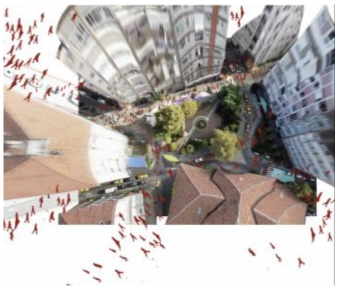
Aim	In this practice, emphasis is placed on the park's inconspicuous presence, deliberately overlooked within the natural course of life. It is highlighted that the park goes unnoticed, remains unexplored, and even upon entry, the spatial elements evade recognition.	
Result	In this study, multiple techniques have been employed. The overhead view of the space is utilized as the main image, and the buildings enclosing and trapping the park are exaggerated using the liquefaction technique. People, absorbed in the flow of the city, pass around the park without noticing or perceiving it. The painting of human silhouettes in red is intended to emphasize the main character and the movement in the flow of the street.	

Table 3. Student 2 representation aim and result

Aim	In this study, which focuses on the Maiden's Tower, it is aimed to combine the myths of the tower from the past to the present with visuals. The myths to be explained are represented by the colors chosen around the Maiden's Tower. The Bosphorus line of the Maiden's Tower, a section of the Üsküdar coast-line and the Istanbul skyline are also reflected in the visuals of the work.	
Result	In conclusion, the 4 legends of the Maiden's Tower are the main figures, with the heartwarming pink sky around the Maiden's Tower at sunset, today's Bosphorus traffic, the use of the Üsküdar coastline and the current silhouette of Istanbul reflected in the background of the work. All the colors used in the stories were chosen from the shades of colors found in the work, including the sky. The reason for this is that this study aims to reflect existing, known myths and all the colors seen in the study are chosen from the reflections of this visual. This expression was combined in an image with the illustration representation method.	

Student 4 focused on the Bosphorus Bridge—now known as the 15 July Martyrs Bridge—highlighting its transformation from an infrastructural landmark to a symbolic monument of national significance. The aim was to explore and represent the events that have imbued the structure with historical weight, particularly the pivotal moment of July 15, through graphic and auditory means. The final video used visual layering, sound, and symbolic imagery to convey the bridge's dual identity: as an engineering marvel shaping Istanbul's skyline, and as a charged cultural site embodying collective memory and national resilience. This approach allowed the student to move beyond a technical portrayal and instead capture the emotive and socio-political layers of architectural meaning. (Table 5)

Table 4. Student 3 representation aim and result

Aim	In this study, it is aimed to offer the audience a visual experience of the historical development of Büyük Hendek Street leading to Galata Tower, through its transformation from the past to the present by providing an architectural representation of the street.	
Result	This study initially emphasized the significant structural differences by revealing the major structural differences in the first three images. Subsequently, in the following visuals, while the street retained its silhouette with minor variations, the focus shifted to highlighting the diverse ways it has been utilized and experienced in daily life. Together with all of these elements, an effort has been made to express how Buyuk Hendek Avenue and its relationship with Galata Tower have undergone changes throughout history.	

Student 5 explored the dynamic spatial experience generated by the arrival of a ferry at the Kadıköy Ferry Pier, with a focus on the concepts of circulation and crowdedness. The aim was to represent the fluid movement patterns and social density associated with this daily urban ritual. Through animated sequences supported by sound effects, the student illustrated each phase of the passenger flow—from the approach of the ferry to the dispersal of the crowd—emphasizing temporal progression and spatial rhythm. This audiovisual approach successfully conveyed the vibrancy and organized chaos typical of Istanbul’s ferry culture, transforming an ordinary transit moment into a rich subject of architectural representation. (Table 6)

Finally, student 6 aimed to investigate the spatial perception of a selected urban area by emphasizing its visual, auditory, and kinetic dimensions. The representation was constructed through a stylized 3D animation that deliberately avoided mimicking real-life camera footage. Instead, the student chose a static, orthographic perspective to abstract and clarify the spatial characteristics of the site. This methodological choice allowed for a more analytical representation, encouraging viewers to focus on spatial relationships, movement patterns, and environmental cues without the distraction of photorealism. The result was a controlled and conceptual exploration of urban perception, reinforcing how representation techniques can shape and guide architectural understanding. (Table 7)

Table 5. Student 4 representation aim and result

Aim	The Bosphorus Bridge is represented architecturally in this study. The events that took place on the bridge will be discussed by graphing them. The representation methods used to express this work will be examined.	
Result	As a result, the 15 July Martyrs Bridge, with its new name, is one of the rare structures that combines aesthetic and technical perfection with its architectural representation. The Bosphorus Bridge is known for the aesthetic value, engineering achievements and symbolic importance it adds to the Istanbul skyline. Moreover, it is not only a transportation structure but also a cultural heritage and source of pride. With this video representation method, these issues are processed graphically and this representation is supported with sounds. In this representation, the story of the Bosphorus Bridge becoming the 15th of July Martyrs Bridge was intended to be told through video and graphics.	

In their final representations, students integrated research findings with symbolic visual strategies, using spatial abstraction, sequencing and narrative devices to express meaning. These representations went beyond literal documentation; they functioned as interpretive mappings of Istanbul's identity, encapsulating the tension between memory and transformation, tradition and modernity. The creative freedom provided in the scenario-building process encouraged students to engage in speculative thinking, resulting in outputs that were both intellectually grounded and emotionally resonant.

Moreover, the studio process fostered active engagement with Istanbul’s urban fabric. Students reported increased awareness of the cultural and historical contexts shaping the city, as well as a deeper appreciation for the role of architecture in reflecting and shaping urban narratives. Peer discussions and critiques contributed to the emergence of shared themes, including temporality, hybridity, and the fragmentation of identity in contemporary urban life.

Table 6. Student 5 representation aim and result

Aim	With the formation of concepts, this study aims to produce a representation of the circulation created by the movement of the ferry arriving at the Kadıköy Ferry Pier.	
Result	In this study it was tried to be represented through the concepts examined. In other words, in this study, animation produces representations of circulation and crowds. Each stage in the flow is shown in order and the work is enhanced with sound effects. That's why, this study aims to produce a representation of the circulation created by the movement of the ferry arriving at the Kadıköy Ferry Pier. The main concepts to be emphasized are circulation and crowded space.	

Table 7. Student 6 representation aim and result

Aim	The purpose of choosing this project area is to examine the spatial perception of the area and draw attention to its various aspects.	
Result	The chosen methodology for examining visual, auditory, and motion-related issues in the project area involves the creaƟon of a 3D animation video. The animation is stylized to avoid resembling a camera video, and a static, orthographic angle is preferred.	

4. Discussion

The findings of this studio practice highlight the pedagogical value of integrating urban identity as a core theme within architectural representation courses. By positioning representation not merely as a technique but as a method of inquiry, the studio encouraged students to think critically about how spatial forms and cultural meanings intersect. The act of selecting and researching an identity element required students to engage with the socio-political and historical dimensions of the place, fostering an understanding of architecture as a cultural and communicative practice.

Across the six student projects, a diverse range of urban identity elements from overlooked green spaces to iconic landmarks like the Maiden's Tower and Bosphorus Bridge were interpreted and represented through various techniques including video, animation, illustration, storytelling frames and graphic composition. Each project uniquely addressed the spatial, historical, and experiential dimensions of Istanbul's urban fabric, emphasizing narrative, symbolism, and perceptual experience. The students demonstrated an ability to translate research into creative outputs, using architectural representation not only as a visual tool but as a medium for critical reflection and meaning-making.

5.Conclusions

This studio practice highlights the pedagogical potential of architectural representation in fostering critical engagement with urban identity. Through the act of representing spatial and cultural elements of Istanbul, students were able to question, interpret, and reframe their understanding of place. As argued by Ockman (2012), architectural education should move beyond skill acquisition to support interpretive and reflective practices that connect students with broader social and cultural narratives. This project aligns with such an approach, offering students a platform to engage with history, memory, and meaning through creative processes.

Moreover, integrating representational media such as video and animation supports the development of visual literacy and narrative competence-skills increasingly emphasized in contemporary architectural education (Kolarevic & Klinger, 2008; Salama, 2015). By situating urban identity at the center of the design inquiry, this project not only enriched students' perception of Istanbul's layered urban fabric but also contributed to a growing body of educational practices that prioritize critical, place-based learning. The results affirm that architectural representation, when applied as a reflective and expressive tool, holds significant value in both design education and urban discourse.

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Reuse trends and current situation in architectural building material research: A bibliometric

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Abstract. The construction industry has a never-ending growth potential, but it also causes significant consumption of global natural resources and generates large amounts of waste. This leads to environmental problems around the world. The global architecture, engineering and construction industry is increasing its efforts to explore and implement sustainable construction methods to solve these problems. This study examines the reuse trends in building material research in architecture through bibliometric analysis. The development trends of the publications in the field of reuse of building materials obtained from Scopus databases in recent years, the relationships between stakeholders such as authors, institutions and countries in this field, and the prominent keywords in the field of study were revealed by bibliometric analysis. The findings show that between 1989-2019, technically oriented concepts such as 'Building Information Modelling (BIM)', 'energy demand' and 'embodied energy' stand out, but in the period 2020-2024, sustainability-based research such as 'sustainability', 'circular economy', 'waste reduction' and 'green building' increased. According to the results of bibliometric analysis, China, USA, UK and Germany are among the countries with the highest number of publications. Circular economy, life cycle assessment (LCA) and CO_2 emission reduction are among the most frequently researched topics for the reuse of building materials. Sustainable material utilisation and waste management are becoming increasingly important in the sector. This study emphasises that future research should focus on low-carbon construction strategies and recycling efficiency. It is also suggested that policy makers and industry professionals should develop new regulations that support circular economy orientated practices.

Keywords: Architectural materials, bibliometric analysis, building materials, recycling, reuse

1.Introduction

The construction industry exhibits substantial potential for perpetual growth and scalability; however, it simultaneously imposes significant strain on global natural resources and is a major contributor to solid waste generation worldwide (Hu & Chong, 2019). This paradoxical situation exacerbates a range of environmental challenges that necessitate urgent and coordinated global responses. In an effort to address these pressing issues, the architecture, engineering, and construction (AEC) sectors are increasingly prioritizing the exploration and adoption of sustainable construction practices aimed at enhancing resource efficiency and mitigating environmental degradation (Jayawardana et al., 2023). Among the emerging frameworks to address these challenges, the Circular Economy (CE) paradigm has garnered growing attention. CE emphasizes the closed-loop utilization of resources, extending material lifespans, and minimizing waste generation through strategies such as reuse, recycling, and product life extension. Nevertheless, despite its widespread promotion, CE remains a concept without a universally agreed-upon definition, leading to variations in its interpretation and application. As highlighted by Moraga et al., CE distinguishes itself from traditional linear economic models by designing goods and products for durability and by facilitating the recovery and reutilization of raw materials (Moraga et al., 2019; O'Grady et al., 2021). The environmental footprint of the construction sector underscores the critical necessity for systemic transformation. It is estimated that building construction activities alone account for approximately 40% of global natural resource consumption and contribute between 35% and 40% of the world's total solid waste output throughout their life cycle (Kamali et al., 2019; Maués et al.,2020). These figures highlight the imperative to integrate circular economy principles into construction processes, thereby promoting a more sustainable, low-carbon, and resource-resilient built environment. When buildings reach the end of their operational lifespan, it is estimated that only 20–30% of construction materials are effectively recycled or reused, highlighting a critical inefficiency in current resource recovery practices (Adams et al., 2017). Furthermore, the construction industry

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faces mounting pressure to not only mitigate the environmental impact of the growing volume of construction and demolition waste but also to enhance the overall efficiency of resource consumption throughout the building lifecycle (Smol et al., 2015).

The academic literature encompasses a diverse range of studies focused on the recycling and reuse of construction materials, widely accessible through various academic databases. These studies generally employ keyword-based search strategies targeting recyclable construction materials. For instance, Nie et al. (2023) explored the transition of the United Arab Emirates (UAE) towards a circular economy, emphasizing the management of construction and demolition waste during the pre-construction phase. Employing a case study methodology, their work advocates for the integration of circular economy practices to foster sustainable construction processes through more effective waste management strategies. Similarly, Suárez-Riera et al. (2024) reviewed methodologies aimed at minimizing the environmental footprint of cement-based materials. Their findings suggest that enhancing the environmental performance of cementitious materials can play a pivotal role in achieving broader sustainability objectives while simultaneously reducing the construction sector's ecological impact. Shaban and Ali (2024) examined the application of Building Information Modeling (BIM) in residential construction projects, highlighting its potential to improve environmental performance. They advocate for the more widespread adoption of BIM-based methodologies as a means to enhance sustainability across the construction industry. Azari et al. (2024) provided an overview of current advancements and future directions related to construction materials and façade systems in the context of energy-efficient building design. Their study underscores the role of innovative material technologies and façade systems in significantly improving the energy performance of buildings. In another study, Lokko et al. (2024) conducted a comparative life cycle assessment of the carbon impacts associated with conventional versus biogenic building materials used in major residential building typologies in Ghana and Senegal. The research contrasts traditional materials such as concrete and steel with biogenic alternatives like bamboo and rammed earth blocks, evaluating carbon emissions across all phases from production to operational energy consumption and end-of-life disposal. Their findings advocate for the promotion of biogenic materials to reduce the carbon footprint of the construction sector and emphasize the need for policy interventions that encourage the use of locally sourced, sustainable materials. Zhu et al. (2024) assessed the environmental impacts of a pavilion designed according to circular economy principles. Their study illustrates how circular architectural practices — particularly those emphasizing disassembly, modularity, and material reusability — can significantly lower carbon emissions associated with material production and disposal. The pavilion, built entirely with recycled and reusable components, demonstrates the practical benefits and scalability of circular design strategies in sustainable architecture. Xiang et al. (2024) investigated strategies to minimize the carbon emissions associated with the production, transportation, and assembly stages of prefabricated buildings. Their analysis identifies material selection, modular design optimization, and improved manufacturing processes as key levers for reducing embodied carbon, emphasizing the importance of innovative approaches to achieve low-carbon prefabricated construction. Finally, Zotova et al. (2024) explored the thermal performance of wall panels manufactured from lignocellulosic by-products, enhanced with bio-based microencapsulated phase change materials (PCMs). Their study highlights the potential of such composite materials to improve energy efficiency in buildings while contributing to the development of sustainable, bio-based construction solutions. Aziminezhad and Taherkhani (2023) conducted a comprehensive bibliometric analysis to examine the application of Building Information Modelling (BIM) in the deconstruction process. Their study systematically reviews the existing literature, identifying how BIM is utilized in building demolition activities, the potential advantages it offers, and emerging research trends within this domain. The authors provide insights into the evolution of scholarly interest by analyzing publication growth, keyword distribution, and thematic developments related to BIM and deconstruction practices.Similarly, Geng et al. (2017) performed a bibliometric analysis focused on scientific research concerning Life Cycle Assessment (LCA) within the construction sector. Their work investigates the breadth of LCA applications in building design and construction, offering a detailed evaluation of research development trajectories, prevailing themes, and future research directions. It was observed that LCA-related studies predominantly address areas such as energy efficiency, carbon footprint mitigation, material optimization, environmental impact assessment, and sustainable design practices. The study further emphasizes the critical need for the integration of LCA methodologies into decision support systems to facilitate their broader adoption in practical building sector applications. In another notable contribution, Wu et al. (2019) conducted a bibliometric analysis of research activities concerning construction and demolition waste (C&DW) management. Their study delineates the evolution of scientific inquiry into C&DW, highlighting key trends related to waste reuse, recycling practices, management strategies, environmental impacts, and economic evaluations. The findings suggest that research in this field is increasingly aligned with broader sustainability initiatives, emphasizing the connections between C&DW management, energy efficiency, and green building practices. Moreover, Owojori et al. (2021) performed a bibliometric review of the scholarly literature on the adaptive reuse of buildings. Their analysis identifies a growing research emphasis on energy consumption, material efficiency, and innovative design strategies within the adaptive reuse context. The study underscores the expanding relevance of adaptive reuse practices in advancing sustainable construction objectives and highlights critical areas for future investigation.

This study employs a comprehensive bibliometric analysis to investigate emerging trends and the current state of research on the reuse of building materials within the field of architecture. The primary objective is to examine how reused materials are represented and utilized in scholarly literature, as well as to identify the purposes for which they are adapted. Publications concerning material reuse were systematically analyzed using the Bibliometrix and Biblioshiny software packages, operating within the R programming environment, based on datasets retrieved from the Web of Science (WoS) Core Collection.

The analytical process was guided by the following research questions:

1. What are the recent developmental trajectories in publications related to the reuse of building materials?
2. How are the relationships among stakeholders—such as authors, institutions, and countries—structured and evolving within this research domain?
3. What are the prominent keywords emerging in this field, and how are these keywords thematically clustered?
4. What are the principal elements, overarching trends, and dominant themes characterizing research on building material reuse at a global scale?

These research questions are designed to provide an in-depth understanding of reuse-oriented investigations in architectural material research and to critically evaluate both the current landscape and potential future directions of the field. By employing bibliometric techniques, the study systematically examines content trends, thematic developments, and scholarly collaborations, thereby offering novel insights into the reuse of waste materials in line with the principles of reuse, reduction, and renewability. Furthermore, this study aims to generate valuable implications for architects, engineers, policymakers, and material suppliers seeking to advance sustainable building practices. It also seeks to identify existing research gaps, key thematic concentrations, and high-impact areas for future scholarly inquiry, contributing to the broader agenda of promoting circular economy strategies within the construction and architectural sectors.

2.Methodology

Bibliometric analysis has become an increasingly popular research method in recent years. This approach examines academic publications by categorizing them typically into articles, authors, and journals (Merigó and Yang, 2017). Bibliometric tools are utilized to analyze academic data and facilitate the construction of a scientific framework based on that data (Gaviria-Marin et al., 2019). In this study, scientific mapping and visualization processes were conducted using software tools such as VOSviewer and Biblioshiny. While VOSviewer visualizes relationships among academic publications through diagrams, Biblioshiny generates data on parameters such as citations, countries, and keywords. Biblioshiny is a product of the Bibliometrix R package and is supported by the Bibliometrix project. In this research, connections among the most highly cited articles were examined through bibliometric analysis. Academic studies published in the Web of Science database were examined to conduct a bibliometric analysis on adaptive reuse**.** The Web of Science Core Collection was selected due to its interdisciplinary scope and comprehensive scientific publication content. In this study, keywords such as "reduce"**,** "reuse"**,** "recycle"**,** "renewable", and "3R" were utilized. In addition, the terms "architectural design" and "architectural building" were also considered to define the focus of the research. The review encompassed academic studies published between 1989 and 2024, focusing on document types such as articles, book chapters, conference papers, and reviews. Only publications written in English were included in the analysis. Based on these criteria, a dataset comprising 359 publications and 1,106 authors was obtained. The steps followed in the research process are illustrated in the PRISMA flow diagram presented in Fig. 1. No additional exclusion criteria were applied, and all retrieved documents were included in the bibliometric analysis.

As a result of the analysis conducted in Scopus, a graph illustrating the number of publications by year is presented in Fig. 2. According to the graph, there was no notable increase in the number of publications between 1989 and 2004. A significant rise is observed between 2005 and 2010. Following 2010, the number of publications began to increase rapidly, and from 2018 onwards, a sharp and fluctuating upward trend has been identified. In this context, the highest number of publications occurred in 2024 (N=38), 2023 (N=34), and 2020 (N=33).

Fig. 3 displays a graph showing the number of documents by subject area in Scopus. According to the graph, the most prominent fields are identified as Engineering (N=244)**,** Environmental Science (N=89)**,** Energy (N=74)**,** Computer Science (N=47)**,** and Materials Science (N=34)**.**

In terms of document types, the distribution is as follows: Article (N=177), Conference Paper (N=152), Review (N=19), Book Chapter (N=6), Conference Review (N=4), and Retracted (N=1).

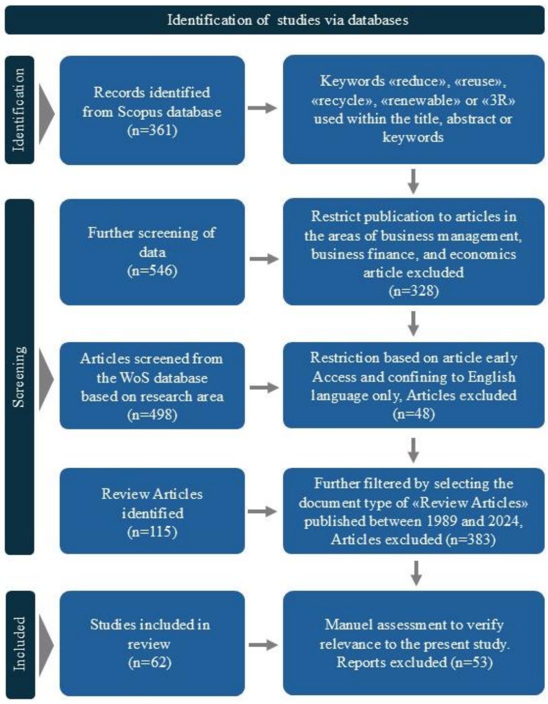

Fig. 1. Prisma flowchart

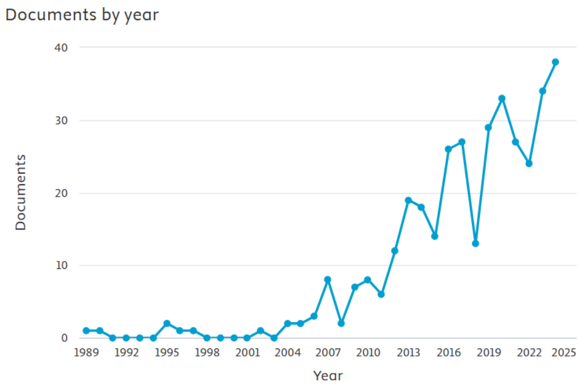

Fig. 2. Documents by year in scopus

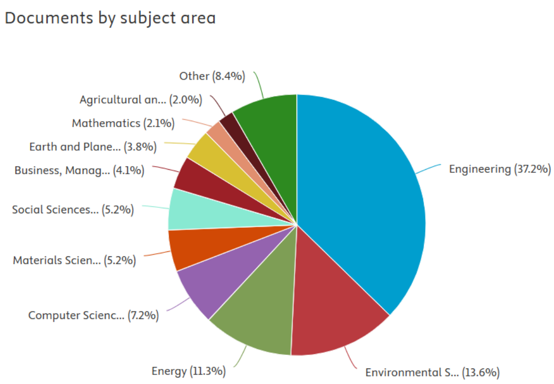

Fig. 3. Documents by subject area in scopus

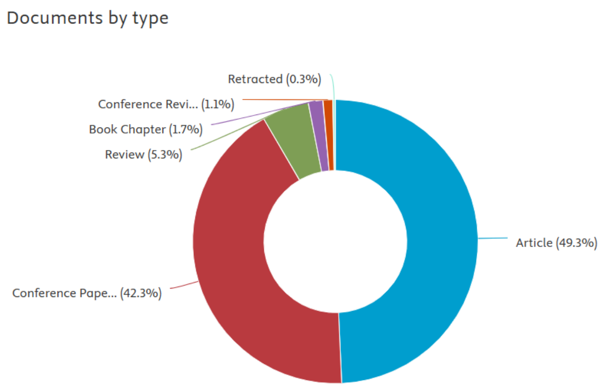

Fig. 4. Documents by type in scopus

A total of 359 documents retrieved from the Scopus database were analyzed using Bibliometrix Biblioshiny within the scope of this study.

3.Results

For the bibliometric analysis conducted using the Bibliometrix R package, documents were retrieved from the Scopus database in CSV format. Only documents written in English were included in the analysis, and any retracted documents were excluded from the study. As a result of these criteria, the main findings of the study are presented below. According to the data, a total of 359 documents published across 192 sources were identified between 1989 and 2024. The analysis revealed 1,106 unique authors, with an annual growth rate of 10.95% and an average citation per year of 21.26. In total, 250 documents were included in the detailed analysis, indicating that the topic has received considerable attention in the academic literature and constitutes an area of significant scholarly interest (Fig. 5). The examined time span from 1989 to 2024 suggests that the field has been the subject of research for approximately 35 years. This highlights both the historical depth of knowledge and the contemporary relevance of the topic within the scientific community.

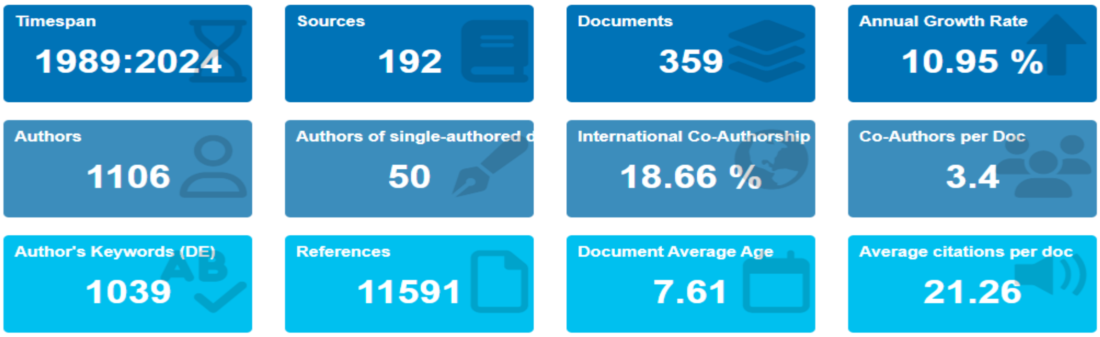

Fig. 5. Main information

Fig. 6 presents a three-field plot, illustrating the relationships among keywords (left), authors (center), and institutions (right). Within this framework, Park Hubei University of Technology, Yonsei University, and Bristol Business School emerge as the most prominent institutions. This visualization effectively demonstrates the connections between specific keywords, authors, and institutions. An analysis of the line density associated with keywords indicates that certain topics are linked to a greater number of authors and institutions. According to the figure, the keywords “building information modeling,” “circular economy,” “sustainability,” and “construction” stand out as the most frequently associated terms. This suggests that these topics are highly popular and actively researched within the scholarly community. The density of the connecting lines reflects the level of collaboration between authors and institutions. Areas with broader collaboration and more extensive knowledge exchange are represented by denser lines. In contrast, topics such as “sustainable building,” “energy consumption,” and “embodied carbon” are associated with fewer connections. This may indicate that these areas are either emerging fields or currently involve lower levels of collaboration.

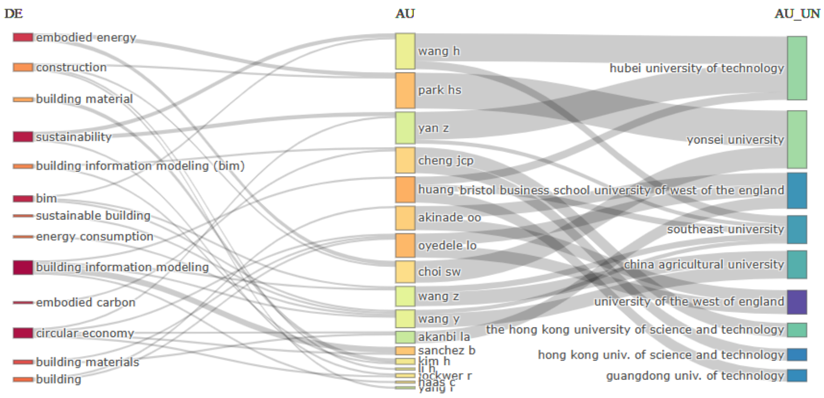

Fig. 6. Three field plot

3.1.Most Relevant Sources

In this bibliometric analysis, the section titled "Most Relevant Sources" examines the leading journals publishing on trends and the current state of reuse in building material research within the field of architecture. The data reveal the sources through which the literature has evolved and highlight the influence of specific journals in shaping the discourse in this area. As illustrated in Fig. 7, the Journal of Cleaner Production stands out as the most prolific source in the literature, with 17 published articles. According to Table 1, the second most active source is the journal Lecture Notes in Civil Engineering. This journal contributes to the discussion from a civil engineering perspective, providing insights into emerging trends related to reuse in architectural building material research. This shows that the study has a strong relationship with engineering practice is the most important. First ranked Journal of Cleaner Production magazine's new magazine on sustainability, energy efficiency and environmental remediation. Focus on issues is an important factor in studies on reuse. Ranked third, Applied Mechanics and Materials magazine is an important source of information for materials science and mechanics source. As a conference, the IOP Conference Series is a particularly innovative and provides an important platform for sharing experimental research. This onesource, research on the reuse of building materials in architecture is a dynamic and constantly evolving field. Energy and Buildings Magazine, which focuses on energy efficiency and building engineering fields, provides valuable information in the context of energy management and sustainable building design with 9 articles. Similarly, the Journal of Building Engineering Magazine, which focuses on building engineering, ensures that sectoral practices are handled on a scientific basis. When Fig. 7 is taken into consideration, Journal of Cleaner Production and Energy and Buildings focus on environment and energy efficiency, while Lecture notes in Civil Engineering and Applied Mechanics and Materials, engineering and technical approaches. In particular, it is noteworthy that publications in magazines such as Journal of Cleaner Production and Lecture Notes are expanded in the context of sustainability and engineering. The conference series allows you to share new ideas and pave the way for innovative solutions.

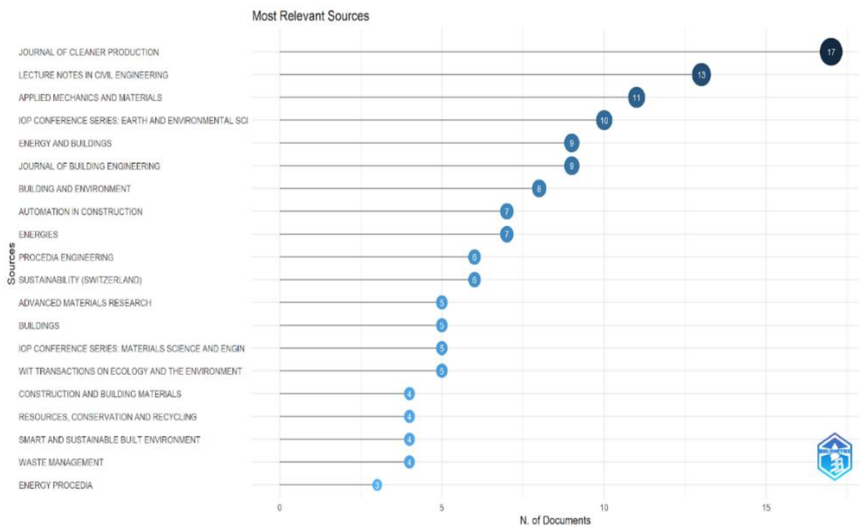

Fig. 7. Most relevant sources

Table 1. Most broadcasting magazines

Magazine name	Article number
Journal Of Cleaner Productıon	17
Lecture Notes In Cıvıl Engıneerıng	13
Applıed Mechanıcs and Materıals	11
Iop Conference Serıes: Earth and Envıronmental Scıence	10
Energy and Buıldıngs	9
Journal of Buıldıng Engıneerıng	9
Journal of Cleaner Productıon	17

3.2.Core Sources by Bradford's Law

The Bradford law is a bibliometric technique used to determine the basic sources of scientific literature on a particular subject. This law examines the distribution of scientific articles between journals on the subject and proposes that a small number of journals should publish intensive publication on a particular issue and the remaining publications should be distributed wider. According to the Bradford Law, three regions are defined. The region, which is described as nuclear region, is comprehensive in a small number of magazines in which most of the articles on the subject are published. When we look at Fig. 8, Journal of Cleaner Production, Lecture Notes in Civil Engineering, Applied Mechanics and Material, IOP Conference Series, Energy and Buildings and Journal of Building Engineering magazines are the core part of the Bradford Law. The so -called second region includes magazines in which fewer articles are published. The magazines between the Building and Enviroment magazine and the IOP Conference Series Materials Science and Engineering constitute the second region (Fig. 8). The third region includes magazines that contain very few articles and are generally indirectly related to the subject. According to Fig. 8, the right side of the IOP Conference Series Materials Science and Engineering magazine is located in this region.

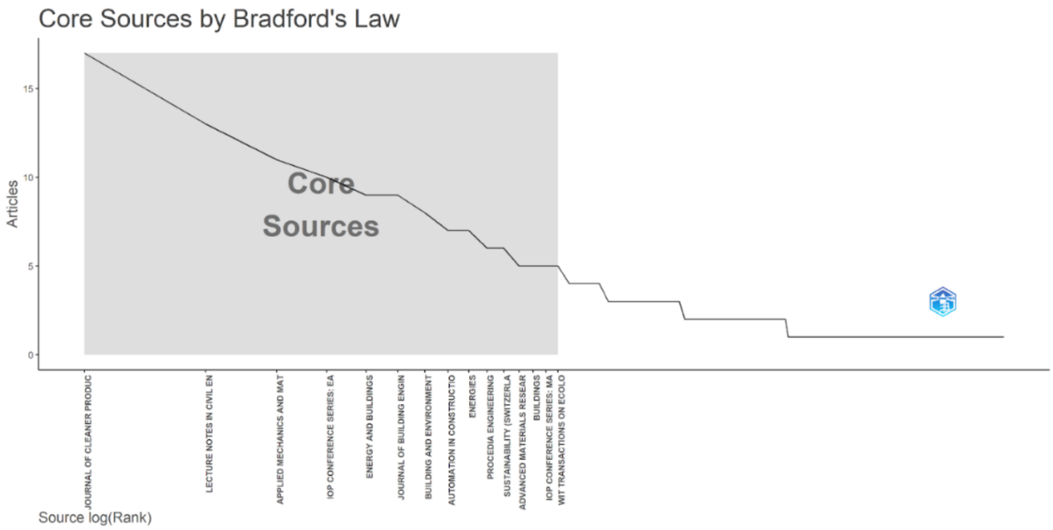

Fig. 8. Core sources by Bradford's law

3.3.Sources' Local Impact

The local impact of a source analyzes the effect of a journal on a particular research area or subject. This measurement usually measures how frequent references to articles published in a journal by other researches in this field. In bibliometric analysis, when evaluating the local influence of a journal, the validity and contribution of an article in a subject or discipline can be better understood. The Journal of Cleaner Production magazine has the highest referenced articles compared to other magazines in this field. This shows that the local influence of the magazine is high. This magazine is considered an important source of information of renewable energy researchers. Building and Enviroment, Energy and Buildings, Journal of Building Engineering, Automation in Construction, Energies, Procedia Engineering magazines, which are less cited in architecture, include disciplinary studies related to the reuse of building materials (Fig. 9).

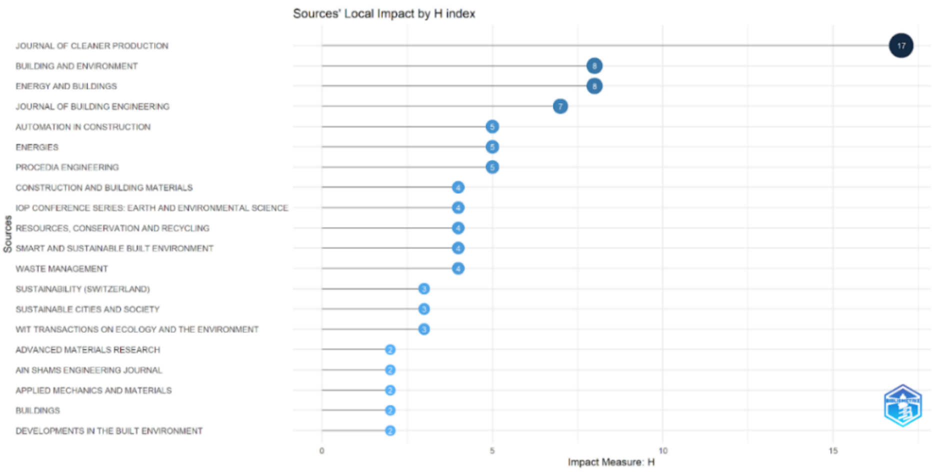

Fig. 9. Sources' Local Impact

3.4.Most Relevant Authors

Most Relevant Authors analysis provides a strategic guide for those who do literature screening and wanting to direct their work by identifying the most effective researchers in an area. The work of these authors is the cornerstones of the information in the field of research. In Fig. 10, all authors show equal productivity with four articles. Considering Table 2, the Park HS has the highest effect score with 0.89, which may indicate that its articles receive more references or more effective than other authors. Huang Y is second with 0.87 and has a similar high effect. Olayle Lo has a lower effect score to 0.65 than others.

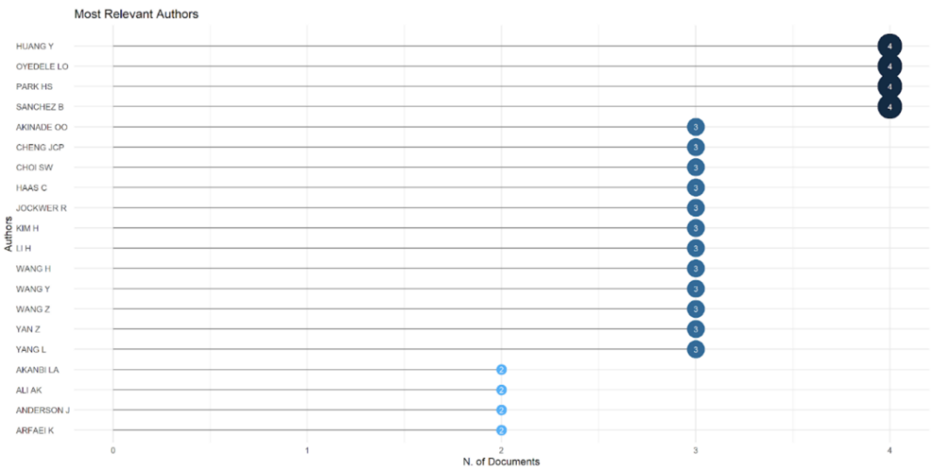

Fig. 10. Most Relevant Authors

Table 2. Number of Articles and Impact Factor

Author	Number of Articles	Impact factor
Huang Y	4	0.87
Oyedele LO	4	0.65
Park HS	4	0.89
Sanchez B	4	

3.5.Authors' Production over Time

Authors 'Production Over Time Analysis is used to examine the productivity of authors' productivity at a certain period of time and the tendencies of their work over the years. This analysis helps to understand the historical development of scientific production, the tendencies of research and the contributions of authors' careers at different points. Oso Lo, Akinade O 2019; Haas C, in 2020, Li H, 2021 (2 publications), Wang Z (2 publications) and Yan Z (3 publications) 2023'te the most broadcasting (Fig. 11).

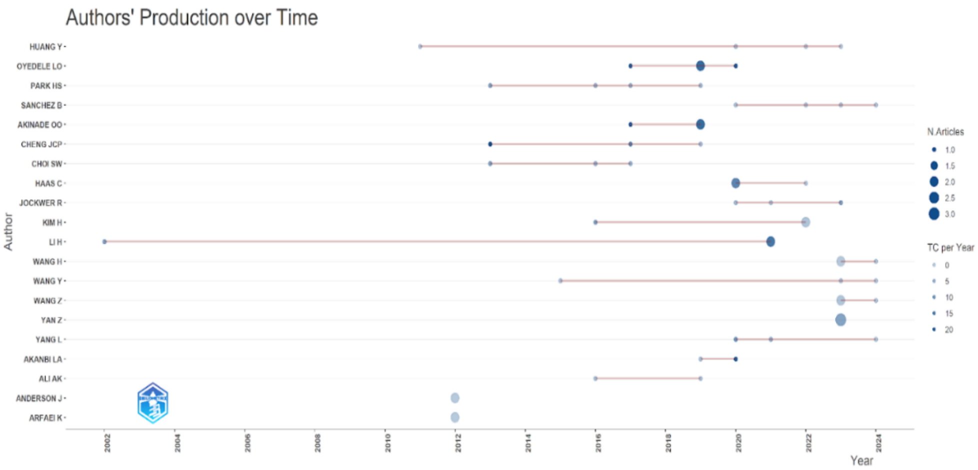

Fig. 11. Authors' Production over Time

3.6.Author Productivity through Lotka's Law

The Lotka Law is a bibliometric model that measures the productivity of writers in a research field and examines the distribution of this productivity. This law proposes a distribution in which a small number of writers broadcast extensively and published only one or two articles by many authors. In the graph, the X axis represents the level of productivity of authors. The Y axis shows the ratio of authors with each productivity level (%) to the total audience. The rapid fall of the flat line shows that high -productivity writers are in the minority, but that few writers play a central role in total information production. These authors can be seen as core information manufacturers in the field. The cut line refers to a theoretical threshold or an important distribution limit in accordance with Lotka's Law. The cut line refers to low productivity authors that make up the majority of authors in the field. This group has made a limited contribution to the literature, but plays a role in the expansion of the area and its spread to different issues. The rapid decrease of the line shows that highly productivity writers are low in number but have a significant effect.

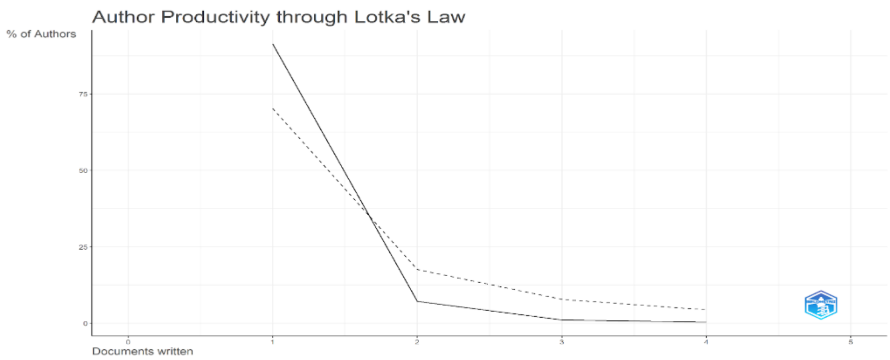

Fig. 12. Author Productivity through Lotka's Law

3.7.Thematic Map

This study employed thematic mapping to identify the major conceptual structures and research trends in the reuse of building materials within architectural research. Using data retrieved from Scopus and visualized through the Bibliometrix platform, thematic maps were generated based on Keyword Plus and Author Keywords. The thematic map based on Keyword Plus revealed four distinct thematic clusters (Fig. 13). *Niche themes* such as *Material Reuse* and *Sustainable Construction* are positioned in the niche quadrant, representing specialized areas with high internal coherence but limited connectivity to the broader research field. These themes are important for targeted advancements but currently exert minimal influence on the wider scholarly network. In contrast, *Motor themes* including *Life Cycle Assessment (LCA)*, *Building Information Modeling (BIM)*, and *Circular Economy* emerged as central, highly developed, and influential topics. Their strategic positioning reflects their critical role in driving innovation and shaping the future direction of sustainable building practices. Meanwhile, *Emerging or Declining themes* were represented by *Building Information Modeling (BIM)*, identified as an increasingly important but still peripheral topic. Although the volume of BIM-related research is growing, its broader integration into sustainability-focused studies remains limited, suggesting significant opportunities for future interdisciplinary research. Finally, *Basic themes* such as *Energy Efficiency*, *Energy Consumption*, *Renewable Energy*, *Embodied*

Carbon, and *Circular Economy* were found to constitute the foundational framework of the research area. Despite their wide-ranging connections across the field, these basic themes require further detailed investigation to strengthen both theoretical understanding and practical applications in sustainable construction and material reuse research.

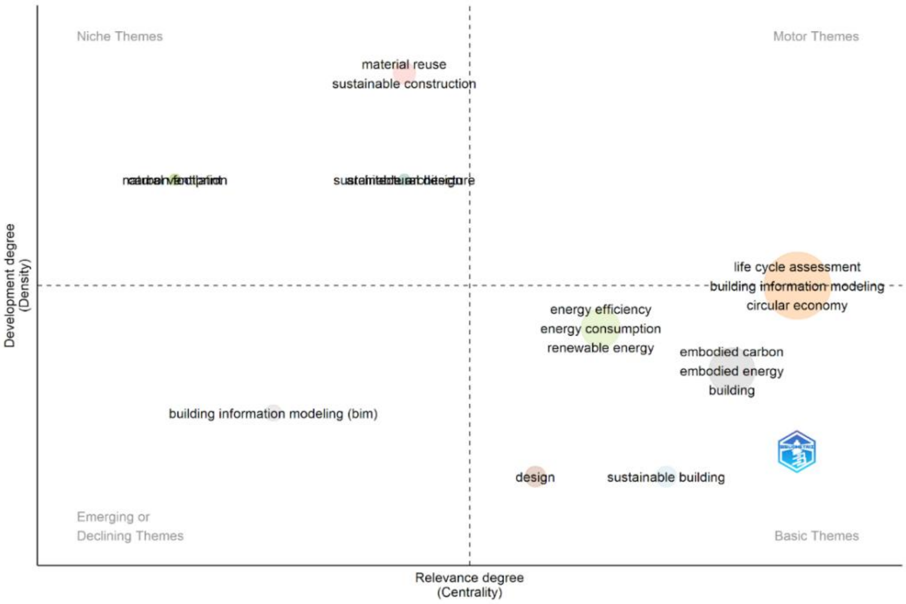

Fig. 13. Thematic Map

The thematic analysis based on Author Keywords (Fig. 14) similarly revealed evolving research structures and emerging focal areas. The *green cluster* represents emerging themes such as *Life Cycle*, *Environmental Impact*, and *Construction Industry*, reflecting an increasing research interest in integrating life cycle assessment methodologies with sustainable construction practices. In contrast, the *red cluster* comprises established themes like *Waste Management* and *Building Materials*, highlighting their central and highly interconnected position within the literature and underscoring their fundamental role in achieving sustainability objectives within the construction sector. The *blue cluster* encompasses niche, technology-driven research areas, including *Energy Conservation*, *Energy Efficiency*, *Energy Utilization*, and *Intelligent Buildings*. These topics are primarily associated with advancements in smart building technologies and energy management systems, representing specialized fields that offer significant opportunities for technological innovation, albeit with relatively limited connections to broader sustainability frameworks.

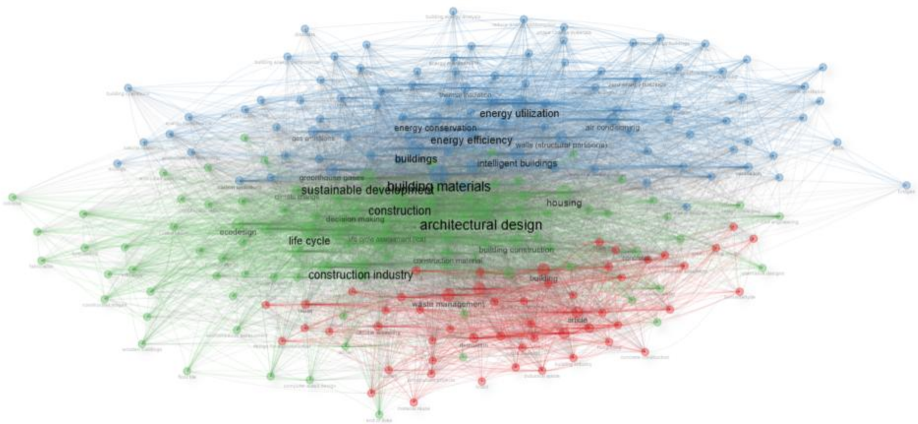

Fig. 14. Thematic Map by Keyword Plus

The comparative analysis of keyword trends from the periods 1989–2019 and 2020–2024 demonstrates a notable thematic shift within the field. Earlier research predominantly concentrated on technical and energy-related topics such as Building Information Modeling (BIM), Embodied Energy, and Energy Demand. However, more recent studies have transitioned towards broader sustainability-oriented concepts, including Circular Economy, Waste Reduction, and Green Building. Likewise, the notion of reuse has evolved from basic resource recovery strategies to more analytically driven frameworks centered on Life Cycle Assessment (LCA) and CO_2 emissions reduction. This thematic evolution underscores the increasing importance of evaluating building material reuse within the contexts of environmental impact, resource optimization, and circular economy principles, reflecting a deeper commitment to achieving comprehensive sustainability in the architecture and construction sectors.

4. Conclusion

This study has presented a comprehensive bibliometric analysis focusing on the reuse of building materials within architectural research, drawing on data from the Scopus database. The findings illuminate the dynamic evolution of scholarly interest in material reuse and highlight key thematic developments in the context of sustainable construction and circular economy frameworks.The analysis reveals a distinct shift in research orientation over the past decades. While studies conducted between 1989 and 2019 predominantly emphasized technical and computational approaches such as Building Information Modeling (BIM), energy demand, and embodied energy, the period from 2020 to 2024 has witnessed a substantial rise in research focused on sustainability, circular economy, waste reduction, and green building design. This indicates a broader transformation in architectural research towards low-carbon, resource-efficient design paradigms. In terms of geographic distribution, China, the United States, the United Kingdom, and several European technical universities have emerged as leading contributors to the academic discourse on sustainable building materials. These regions play a pivotal role in advancing innovation and setting the research agenda in the field. The most prominent studies reflect growing attention to life cycle assessment (LCA), carbon emission mitigation, and construction waste management. In parallel, there is an increased emphasis on adaptive reuse practices and circular design principles aimed at extending the lifespan of materials and reducing environmental impact. Notably, the integration of BIM technologies to support sustainability assessment has gained momentum, further reinforcing the synergy between digital innovation and environmental performance.

Based on the insights gained, this study underscores the following key implications:

- The use of sustainable and recyclable materials should be prioritized in architectural practice to align with global sustainability goals.
- Circular economy principles must be further integrated into the design, construction, and policy-making processes.
- Future research should focus on the development of quantitative frameworks to assess material reuse efficiency, the optimization of waste management systems, and the adoption of low-carbon construction strategies.
- Policymakers and industry stakeholders should work collaboratively to establish regulations and incentives that support the adoption of circular construction practices.

In conclusion, advancing research and practice in building material reuse is essential for the transition to a more sustainable and resilient built environment. This study contributes to the body of knowledge by mapping current research trajectories, identifying gaps, and providing directions for future scholarly inquiry in architecture and construction.

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A cost-effective optimization of post-fire strengthening of concrete columns with FRP fabrics using heuristic algorithm

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Abstract. Reinforced concrete (RC) structural elements exposed to fire suffer various losses in terms of their mechanical properties depending on the maximum temperature and the duration of the fire. In most cases, RC structures that have been exposed to fire require repair and/or retrofitting work on an element or system basis, depending on the extent of the fire damage. The method of circumferential wrapping fiber reinforced polymer (FRP) fabrics is an innovative method for this purpose. Given that the columns are generally main load-bearing members in RC structures, their post-fire performance is of vital importance to ensure structural safety after fire events. This study aims to develop a systematic approach to optimize post-fire retrofitting techniques for critical load-bearing elements. For this purpose, a heuristic algorithm is used. In the algorithm design, the number of FRP layers and the mechanical properties of FRP were chosen as variables. Genetic algorithms were used to identify the optimal combination of FRP composite type and layer quantity to restore and enhance structural integrity. The optimization framework focuses on minimizing costs while maximizing the load-bearing capacity and deformability of fire-damaged columns. The study highlights the role of advanced computational techniques in improving post-disaster recovery strategies for RC buildings. By combining material selection and cost efficiency, this research contributes to the broader field of sustainable structural retrofitting. The results demonstrate the potential of heuristic algorithms in guiding decision-making processes for the repair of fire-affected infrastructure.

Keywords: Concrete Column; Fiber-Reinforced Polymer; Genetic Algorithm; Heat-Damaged; Optimization

1. Introduction

Numerous studies were conducted to investigate the behavior of RC structures at elevated temperatures. The composition of reinforced concrete (RC) includes not only solid components but also a capillary porous structure that contains gaseous and partially vaporized forms of liquid (Bajc et al., 2022). It is known that the behavior of concrete at elevated temperatures changes according to the type of aggregate used in the mixture of concrete (Bilow & Kamara, 2008), while the evaporation of the water in it also has an impact on behavior (Khoury, 2000). This change can be explained by the deterioration of material properties at elevated temperatures, the restraint condition caused by thermal expansion, and the redistribution of structural loads during high temperatures (Qiu et al., 2021). Therefore, heat-damaged RC structures fail to fulfill the requirements in terms of structural safety (Ma et al., 2019).

According to the research conducted in the last decades, there are several recommended strengthening methods for RC structures after fire. Among the main strengthening methods for RC structural members, concrete, steel, or FRP jacketing methods stand out as most commonly known techniques. Due to its easy implementation, high efficiency, and low cost, FRP strengthening methods are becoming increasingly popular within this context (Baji et al., 2018). FRP can be defined as a composite product namely reinforced with carbon, glass, basalt, and aramid fibers, and it is mostly used with epoxy, which is mostly based on vinyl (Alberto, 2013). It is primarily aimed to increase the ductility of RC structural elements with FRP strengthening methods (Awoyera et al., 2024). It has been shown that a significant increase in strength and ductility can be achieved by using FRP strengthening methods in concrete columns after fire (Bisby et al.,2011; Lenwari et al., 2016; Demir et al., 2019; Ouyang et al., 2021; Song et al., 2021; Elhamnike et al., 2022). Moreover, it is acknowledged that the strengthening of RC structures is preferably done only once within the service life of the building. For this reason, the strengthening process to be carried out should be carried out in the most optimal scenario possible. Optimization, as a description, is the tool that finds the best solution within all possible solutions (Dede, 2019). There is limited research where FRP strengthening of RC structures was evaluated in terms of cost (Zou et al., 2007; Choi et al., 2014; Chisari & Bedon, 2016; Chisari & Bedon, 2017; Choi, 2017). The utilization of FRP at the design stage and strengthening

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of heat-damaged RC structures should be evaluated to optimize the cost while meeting the criteria of relevant standards.

According to the best literature survey of the authors, there is no study in the literature that comparatively recommends the most suitable strengthening methods to reduce the cost of FRP material by considering optimization methods based on the performance of heat-damaged structures. In this study, a methodology to find the optimum cost of strengthening and the number of required FRP layers for heat-damaged RC columns strengthened with FRP wrapping is proposed. This procedure is based on a cost-dependent reliability method. Despite the fact that carbon FRP (CFRP) sheets are more commonly demanded in practical strengthening applications in Türkiye, findings reveal that using GFRP can provide sufficient and optimal structural performance under post-heated conditions while reducing overall strengthening expenses.

2. Materials and Methods

Elevated temperatures are known to significantly reduce the compressive strength of concrete Fig. 1. However, an increase in strain values is observed compared to the initial case, unheated state (Bisby et al., 2011). As previously discussed, the loss in compressive strength can be partially recovered through confinement with FRPs. To estimate the axial stress–strain response of heat-damaged concrete itself, the model proposed by (Chang et al., 2006) is used within the scope of this study. In this model, $f_{c\Theta}$ is the unconfined compressive strength of heated concrete after cooling, f_c is the unconfined compressive strength of unheated concrete, $\varepsilon_{c\Theta}$ is the unconfined axial strain of heated concrete after cooling, ε_c is the unconfined axial strain of unheated concrete, and T_m is the maximum temperature. These variables are employed in Equations (1–3), as recommended by (Chang et al., 2006). It is also noteworthy in this study that the heating scenario includes two target temperatures, 300°C and 500°C, which are used in the application of Equations (1–3).

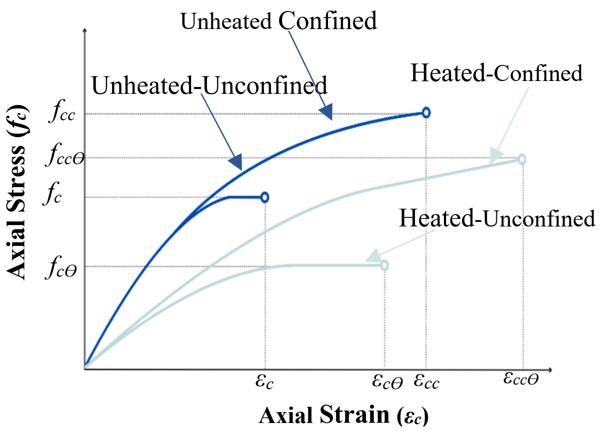


Fig. 1. Stress-strain behavior for the unconfined and FRP-confined concrete at ambient and elevated temperatures (adapted from Bisby et al. 2011)

$$f_{c\Theta} = (1.01 - 0{,}00055)T_m \quad 20°C \leq \; T_m \leq 200°C \tag{1}$$

$$f_{c\Theta} = (1.15 - 0{,}00125)T_m \quad 200°C \leq \; T_m \leq 800°C \tag{2}$$

$$\varepsilon_{c\Theta} = ((7.7 - 0.1f_c)(\frac{e^{0{,}01\times T_m - 5{,}8}}{e^{0{,}01\times T_m - 5{,}8}+1} \text{ - } 0.0219) + 1)\; \varepsilon_c\;) \tag{3}$$

2.1. FRP Confinement Model for Heat-Damaged Concrete

In the literature, many experimental studies have been carried out to predict the stress-strain behavior of FRP-confined heat-damaged concrete. ACI 440.2R-17 models have been modified in this regard to predict the ultimate condition of FRP-confined unheated concrete. With this aim, a model based on ACI 440.2R-17 was developed by (Bisby et al., 2011), as summarized in Eqs. (4-9). In these equations, $f_{cc\Theta}$,the compressive strength of FRP-confined heat-damaged concrete is first calculated. The effective confinement pressure (f_{lu}) is calculated using Eq. 5, where E_f is the modulus of elasticity of the FRP wrap in the hoop direction, $\varepsilon_{f\varepsilon}$ is the effective strain in the FRP wrap at the ultimate state, and the thickness of the FRP is shown by t_f. The effective strain in the FRP at failure, $\varepsilon_{f\varepsilon}$, is calculated using Eq. 6, where k_ε is the strain efficiency factor and ε_{fu} is the design rupture strain of the FRP wrap. In addition, in Equations (7-9), $\varepsilon_{cc\Theta}$ is the ultimate strain of heated concrete after FRP confinement, while

ε_{cc} is the ultimate strain in FRP-confined unheated concrete.

$$f_{cc\Theta} = f_{c\Theta} + 3.3 f_{lu} \quad (4)$$

$$f_{lu} = \frac{2 n t_f E_f \varepsilon_f}{D} \quad (5)$$

$$\varepsilon_{f\varepsilon} = \varepsilon_{fu} k_\varepsilon \quad (6)$$

$$\varepsilon_{cc\Theta} = \varepsilon_{c\Theta} + (\varepsilon_{cc} - \varepsilon_c) \quad (7)$$

$$\varepsilon_{cc} = \frac{1.71(5 f_{cc} - 4 f_c)}{E_c} \quad (8)$$

$$E_c = \frac{2 f_c}{\varepsilon_c} \quad (9)$$

2.2 FRP Types

Glass, basalt, carbon, and aramid fibers are the most used materials to produce FRP composites, and they all have different physical and mechanical behavior (Nanni et al., 2014). The most used fiber in the materials of FRP is glass fiber reinforced polymer (GFRP) because of its relatively lower price (Khodadadi et al., 2024). Besides, CFRP has a wide range in terms of application fields, although its price is relatively high many times. In addition, substantial qualifications of carbon FRPs, including their sensitivity to creep rupture, resistance to alkaline and acidic solutions, and capacity to absorb higher sustained stresses, make them a satisfying material in many applications such as prestressing (ACI 440.2R-17). On the other hand, basalt fiber polymer (BFRP) is made from melted basalt rocks. Due to the mechanical qualifications of BFRP and satisfactory price, the use of BFRP is increasing (Khodadadi et al., 2024). In literature, researchers are developing various methods to eliminate the negative aspects of aramid FRP, such as physical methods, chemical grafting, coating methods, and nanostructures (Zhang et al., 2021). Fibers are the load-bearing components of FRP, and the type to be applied has a critical impact on the mechanical behavior of heat-damaged concrete. Considering this, information about the four types of commonly used FRPs is comparatively presented in Table 1. The data was compiled from different exporters in Türkiye.

Table 1. FRP Properties

FRP Type	E_f (GPa)	f_f (MPa)	t_f (mm)	ε_{fu} (%)	Cost per m^3
CFRP-1	228	1600	0.11	0.02	9$
CFRP-2	228	2000	0.11	0.02	10$
CFRP-3	228	3000	0.11	0.02	11$
CFRP-4	228	4000	0.11	0.02	12$
GFRP-1	76	3450	0.35	0.02	1$
GFRP-2	97	4830	0.35	0.02	1.5$
BFRP-1	85	2900	0.12	0.02	2.5$
BFRP-2	86	3000	0.12	0.02	3$
BFRP-3	87	3100	0.12	0.02	4$
AFRP	118	2060	0.19	0.02	5$

2.3. Optimization Problem

Axial compressive strength and the ultimate strain of the concrete depend on several effects, including but not limited to i) the thickness, ii) tensile strength and iii) elastic modulus of the confining FRP, iv) unconfined concrete strength, and v) cross-sectional shape of the column. As shown in Fig. 2, within the scope of this study, a hypothetical column is confined with various configurations of FRP wrap after being exposed to fire. The cost of strengthening configuration was calculated through Equations (10-12), where V_f is defined as the volume of FRP, C_f is the circumference (mm) of FRP, and μ is the cost of epoxy. In addition, V_o defines the volume of overlap length (mm) of FRP, n_f indicates the number of layers of FRP, δ is the cost per volume. The cost equations used in this study (Eqs. (10-12) are adopted based on the expressions given by Zou et al. (2007), with some modifications in terms of full wrapping conditions of the columns, which are not considered by Zou et al. (2007).

The proposed scenario is applied over 100 cm (D)×200 cm (L_f) cylindrical column with 100mm overlap length of FRP, which is shown in Fig.2. Initial compressive strength *(f_c)* of the column was assumed to be 28 MPa and the initial axial strain *(ε_c)* of the column was adjusted to 0,002 at the beginning of the heating process. Increase at confined-heat-damaged compressive strength and axial strain with respect to the initial cases (before fire) was calculated by gain functions given at Eq. (13). To put it more simple, compressive strength gain per axial strain gain defined as gain ratio. In practical FRP applications after a fire event, it is usually aimed to increase the deformability of the column members rather than its strength. This phenomenon may vary depending on the location of the intervened building i.e. in relation with the residual seismic risk after fire (Demir et al., 2020a, b). Therefore, in objective function (f_{opt}), the goal is to make the most of confined compressive strength while maximizing axial strain, and the meantime keeping cost to a minimum. Gain ratio per cost is the aim of the algorithm, which is desired to be maximized. Compressive strength and axial strain vary relative to each other depending on the selection of FRP. The reason for the boundary of compressive strength is that, at least it is expected to be equal or more than at the value of initial compressive strength. Moreover, maximum axial strain value recommended by ACI 440.2R-17 is 0.01, but experimental studies show that the value allowed can go up to 0.02 (Bisby et al., 2011).So that, if the ultimate axial strain falls within the 0.01-0.02 range, rather than forcing it to higher strain gain values, it is preferable to increase gain ratio while remaining in the ultimate axial strain range. Considering these limitations, possible minimum conditions are constrained by strength ratio, and possible maximum conditions are constrained by strain ratio. This phenomenon is applied to the optimization process using Eq. (15).

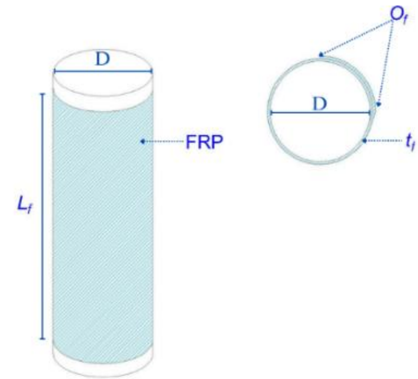


Fig. 2. FRP wrapping of columns.

$$\text{Minimum Cost } = \left(V_f \times n_f + V_o\right)\delta + \mu \times n_f \tag{10}$$

$$V_f = L_f \times C_f \times t_f \tag{11}$$

$$V_o = L_f \times O_f \times t_f \tag{12}$$

$$\text{Compressive Strength Gain: } \frac{f_{cc\Theta} - f_c}{f_c} \tag{13a}$$

$$\text{Axial Strain Gain: } \frac{\varepsilon_{cc\Theta} - \varepsilon_c}{\varepsilon_c} \tag{13b}$$

$$\text{Objective Function} \qquad f_{opt} = \frac{\left(\frac{f_{cc\Theta} - f_c}{f_c}\right)}{(V_f n_f + V_o)\delta \times \left(\frac{\varepsilon_{cc\Theta} - \varepsilon_c}{\varepsilon_c}\right)} \tag{14}$$

$$\text{Constraint Condition 1} \quad \varepsilon_{cc\Theta} \leq 0{,}02 \tag{15a}$$

$$\text{Constraint Condition 1} \quad f_c \leq f_{cc\Theta} \tag{15b}$$

2.4. Optimization Algorithm

The optimization algorithm used in this research is based on genetic algorithms (GA), which can be used in Grasshopper® interface, a Rhinoceros® (Mcneel, 2010) plug-in. The model uses Grasshopper's Galapagos tool for GA optimization. The main idea in this algorithm is to ensure that a population of many genes evolves and tries to find optimum scenario. The choice of the parameters used in GA depends on the problem. Basically, while some of the parameters control the investigation capabilities of the algorithm, such as population size, some of the parameters conduct the evolution of algorithms. The initial population is generated randomly in this approach, to prevent manipulating the evaluation of algorithms. It was inferred that the following initial conditions were adequate for solving the problem of this study:

- Population size: 10 individuals.
- Number of Generations: 20.

The procedure for finding the optimum number of FRP layers is presented via the flowchart shown in Fig. 3. Steps of this procedure can be summarized as follows:

1. Inputting the required information such as mechanical properties (E_f, f_f, t_f, ε_{fc}) and cost per volume of FRP, cost per volume of epoxy, maximum temperature reached (T_m), geometry of columns (D and L_f) and optionally the corresponding constraints of strain and strength which in default fixed as in Eq. (17),
2. Proceed with calculations of cost, gain functions as well as objective function than record the result,
3. Based on the given list of FRP, try all possible configurations,
4. Compare all the results and decide the optimal scenario based on the objective function.

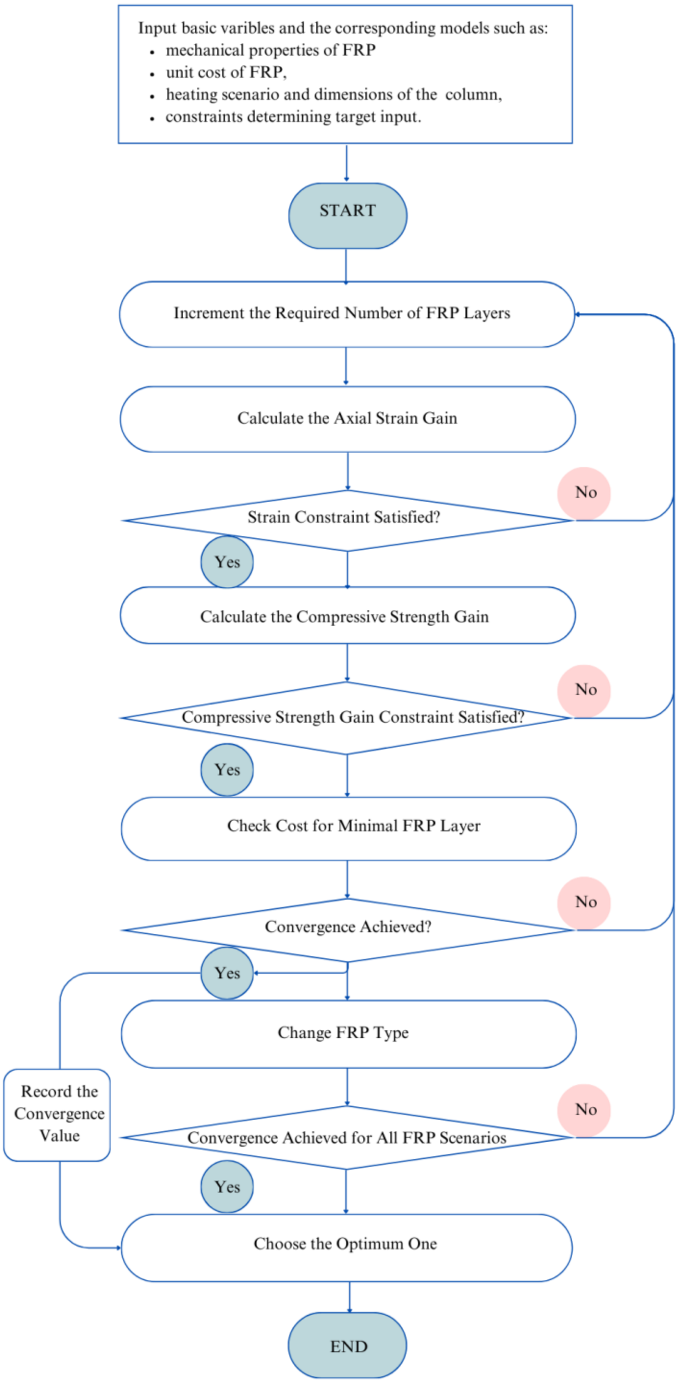


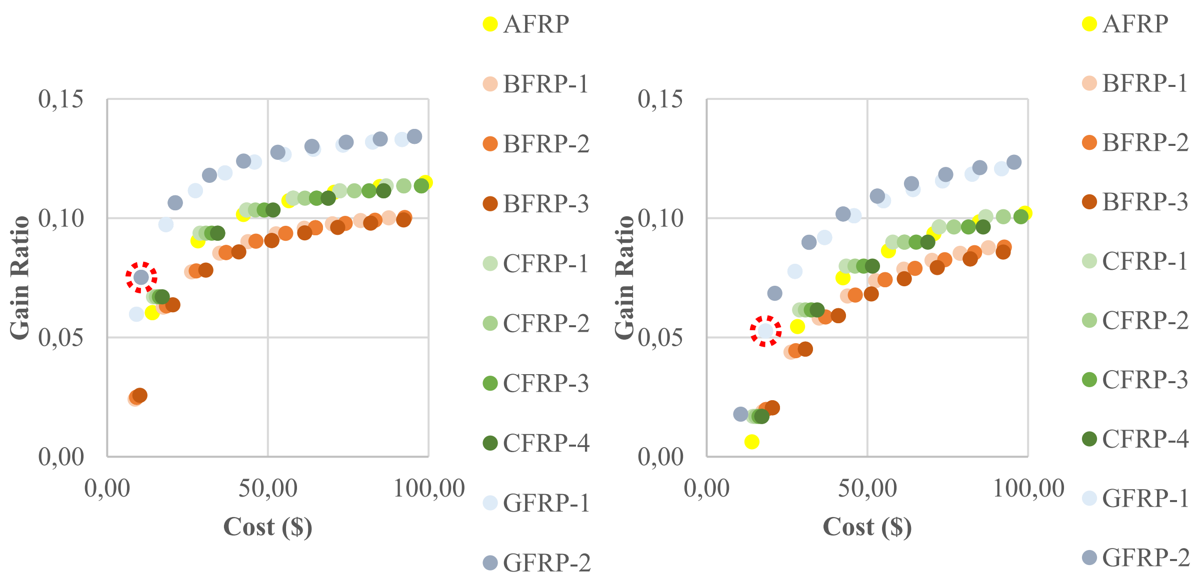
Fig. 3. Algorithm approach for finding the best FRP scenario.

3. Results

In the parameters configured according to the features specified in the previous section, genetic algorithm was used to achieve optimum scenario of FRP implementation on a concrete column. At the beginning of the process, the algorithm initialized with random values, to provide fair approach. The values circled in red in the graphs represent the optimal results. The relationship between the cost per volume of FRP and the gain ratio for different types of FRP is shown in Fig.4. In general, CFRP and GFRP wraps show higher gain ratios compared to AFRP and BFRP wraps. It has been seen that GFRP wraps performed the optimal results at both temperatures. The reason behind this scenario can be explained by Fig.5 as the slope of GFRP curve is greater compared to others. Also, this is expected due to most confined compressive strength gain per axial strain gain was beginning target of whole process. Thus, the algorithm converged to GFRP wrap. A notable improvement in stress-strain relationship was observed by confining GFRP-2 with one layer, at 300 °C. The value of compressive strength is observed to increase %135.7, and the value of axial strain has experienced a fivefold increase, as shown in Fig.5a. The corresponding cost has been determined to be \$10.63. On the other hand, two layers of GFRP-1 were confined at 500°C, which led to the achievement of the optimal result. The value of compressive strength is seen as to increase %142,8, and the value of axial strain has experienced a ninefold increase in this case, as seen in Fig.5b. The calculated cost for this scenario is \$18.36.

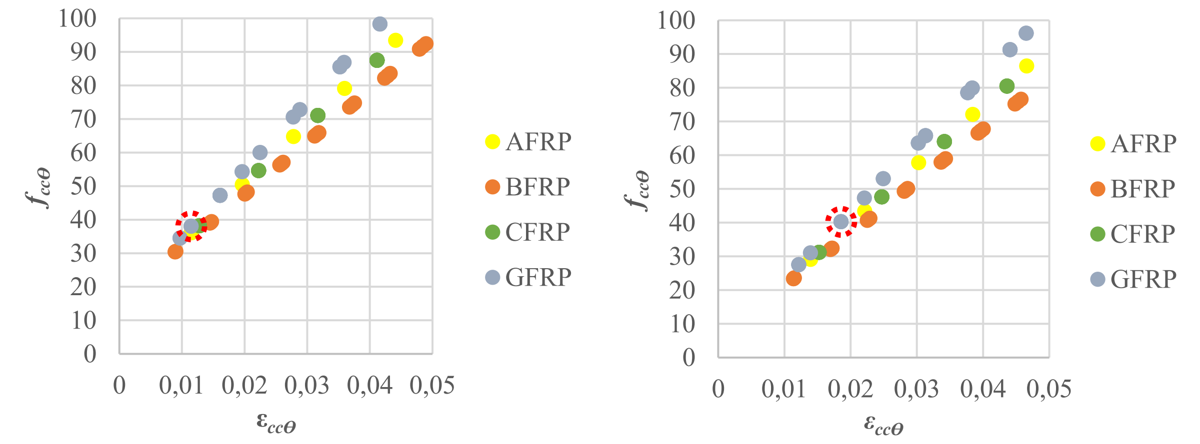
In Fig.6, the optimization process across iterations under different temperatures is presented. While the y axis represents gain ratio per cost values, the x axis shows the progression across iterations in algorithms. In each iteration, notable changes in FRP selection can be detected based on populations. In general, the reason why some genes of population are clustered between 0 and 0,001 is due to the high number of layers of FRP leading to increased costs. On the other hand, GFRP was found to be dominant at both temperatures. However, the performance of one-layer of GFRP-2 is followed by one-layer GFRP-1 and CFRP wraps and comprise a possible second choice for efficient strengthening at 300°C. Also, two layers of GFRP-1 observed as a unique wrap with no equivalent among other wraps at 500°C. The interesting point here is that some FRP confined-heat damaged concrete with one layer confinement have been observed to be unable to achieve the initial compressive strength. Thus, some genes failed to revert to their initial condition and remained under the 0 line, such as one-layer BFRP-1, BFRP-2, BFRP-3, and GFRP-1 at 500°C.

Based on these results, the effectiveness and efficiency of the proposed strengthening methods at different temperatures are emphasized. It has been observed that the process can be completed in a limited number of iterations, since the problem in this study can be considered as non-complex and includes only a few options to use as a parameter in GA. It is considered that this situation defines the reason behind scarcity in iterations.



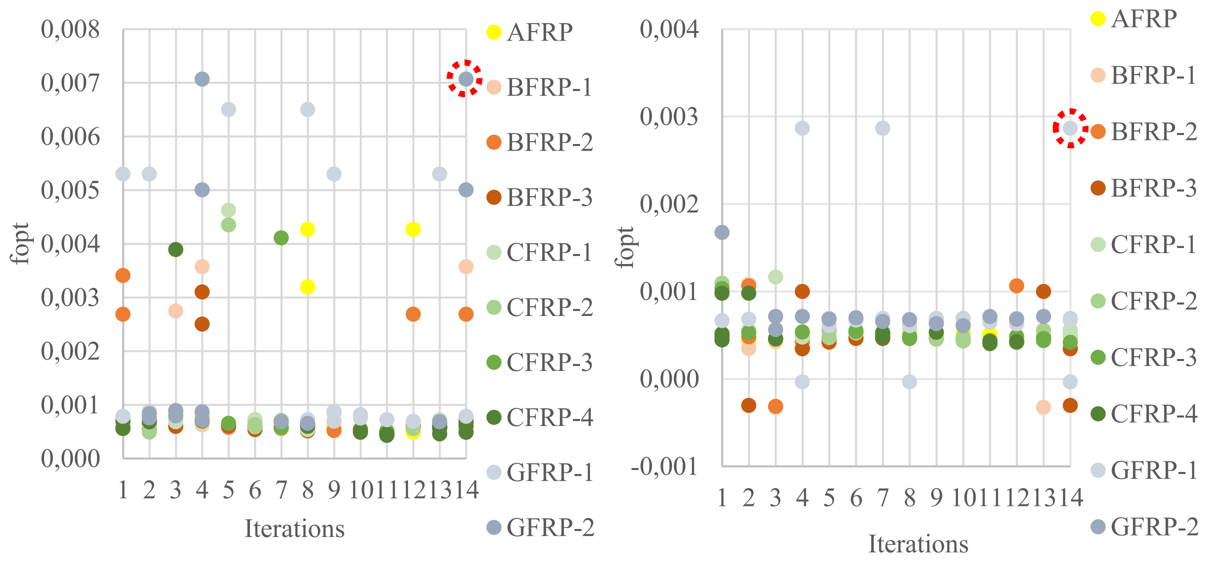
a) b)

Fig. 4. The results of gain ratios versus cost at a) 300°, b) 500°C.



a) b)

Fig. 5 Stress-Strain behavior of confined-heat-damaged concrete at a) 300°, b) 500°C.



a) b)

Fig.6 Optimization progress plot at a) 300°, b) 500°C.,

4. Conclusions

This study presents a performance-based optimization in GA for the cost-effective selection of FRP types, and their layers used in strengthening concrete columns after fire exposure. According to the optimization approach, it was aimed to achieve maximum gain in strength of the heat-damaged column after wrapping, while also considering the feasible state, in the range of 0.01-0.02, for ultimate axial strain, at the state of minimum cost. The constraints of objective function were determined on the base of the minimum limit of $f_{cc\Theta}$ and maximum limit of $\varepsilon_{cc\Theta}$. Two different temperature scenarios were used in optimization process, 300° and 500°C.

The results highlighted that optimization approach was able to find the most effective cost with the highest gain ratio. In addition, it was determined that GA evolves towards the completion of the optimization process and finds the most optimal result at different temperatures. While optimum scenario for 300°C was found as wrapping the column specimen with one-layer of GFRP-2, two-layer of GFRP-1 exhibited the most cost-effective solution for the column specimen at 500°C.

It has to be noted that this technique defines only a prototype, considering the scarcity of parameters and possible solutions. It is suggested that the prototype should be improved to solve a more complex scenario, such including a notable number of FRP types and a case study application on a sample compartment, which includes multiple columns.

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The millennium tent: A critical review on Astana Khan Shatyr

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Abstract. Tents, the most primitive form of shelter, can be seen as traditional tensile architecture. Although the tent structure has existed for thousands of years, tents still offer a valuable starting point for designing modern tensile buildings. However, to enhance large-span modern tensile architecture, it is crucial to understand the inherent structural characteristics of the membrane rather than simply mimicking the form of tents. Thus, the rediscovery of traditional tensile buildings through advanced technology presents an opportunity to liberate architecture from the constraints of heavy formal designs. In this context, this paper examines the impact of tensile structures on form development and focuses on one notable modern tent-like building, Khan Shatyr (Tent of the Khan). This research introduces the Khan Shatyr project by Foster and Partners and explores its significance within modern tensile structures. The relationships between form and concept, material properties, and structural behavior of the Khan Shatyr are evaluated. In conclusion, the Khan Shatyr project is critically analyzed in terms of its architectural form, its interplay with its structural design, and its role as a megastructure. The study highlights how the project transcends traditional tensile design principles by leveraging advanced materials and innovative engineering. This examination underscores the redefined modern architecture by balancing form, functionality, and structural efficiency. Ultimately, the study highlights the challenges of translating traditional tensile principles into modern megastructures, raising questions about the balance between architectural expression and structural behavior in contemporary design.

Keywords: Millennium tent; Tensile structures; Megastructures; Astana Khan Shatyr

1. Introduction

Tents were some of the first and most successful fabric tensile constructions. Tent structures were built to provide a big enclosed space, seclusion, environmental adjustment, and protection under a fabric covering. Modern and complicated fabric structures originated from primordial tent structures by breaking away from the symbolic shape of vernacular tents. Furthermore, with technological advances in structural engineering, architects made structures more appealing by focusing on the new functional aesthetic (Kamal, 2020). Fabric membrane constructions have existed for millennia as simple, tent-like shelters. The guy ropes and tent poles in tents provide pretension to the fabric, allowing the structure to endure wind, rain, and snow loads.

This paper investigates the influence of tensile structures on form evaluation, with a focus on one noteworthy modern tent-like structure, Khan Shatyr (Tent of the Khan). The structural features of tensile structures are investigated. In the context of this paper, prior knowledge about cable structural systems is provided. The Khan Shatyr Entertainment Center in Astana is examined as a case study of cable-net tensile structures. The Khan Shatyr's form-concept relationships, material qualities, and structural behavior are all analyzed. Finally, the Khan Shatyr project is critically examined in terms of architectural form, structural design, and megastructure function.

2. Tensile Structures

Tensile membrane systems, which include cable net structures, shells, folded plates, and grid-domes, can only withstand tension loads (Berger, 1999), not compression or bending. These structures may span huge distances with little weight on their supports (Kamal, 2020), and advances in fabric technology are influencing building design methodologies. Tensile structures stretch membranes to form a three-dimensional surface, which is often supported by compression or bending elements such as masts, compression rings, and beams. Tensile structures have the advantage of being lightweight; the prestressed forms of the membranes provide design flexibility, allowing for large spans with less weight. Furthermore, the lightweight nature of these tensile components allows for easier transportation and assembly of the structures. The Olympia Roof in Munich, 1972, designed by Frei Otto and Bennish & Partners (Henrysson, 2012) can be considered a tension structural milestone. Its cable net structure on a vast scale gives up new possibilities in computer structural analysis and shape finding approaches.

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One of the most significant stages in designing tensile structures is the form finding process. According to Henrysson's (2012) research, tensile fabric structures only bear tension stresses, hence the majority of tensile fabric systems are anticlastic. Fig. 1 depicts some of these anticlastic shapes, including a conic, a hyper, and a barrel vault/arch support. Under heavy loads, prestressed anticlastic textiles are in tension in at least one direction.

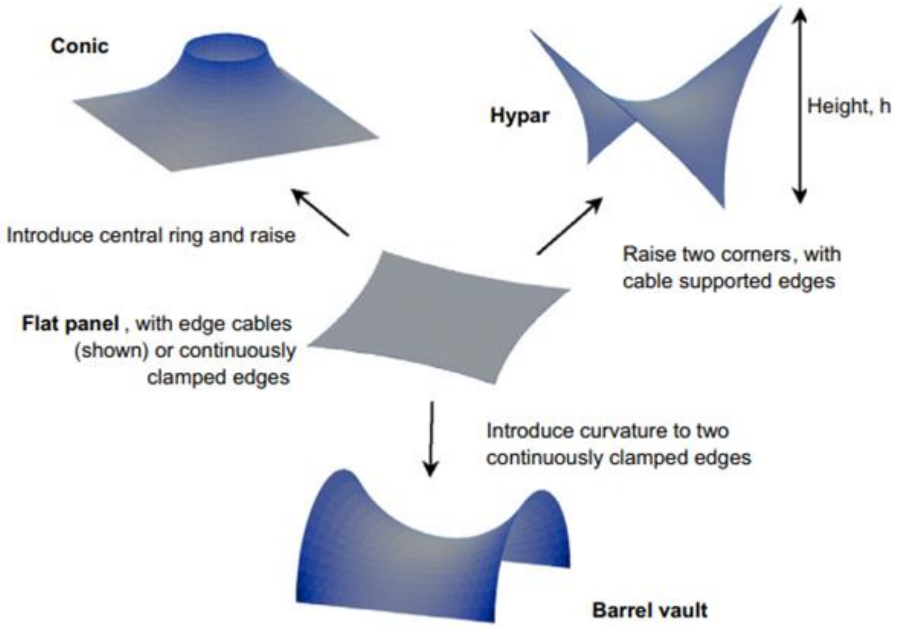


Fig. 1. Anticlastic structures with (a) conic (b) hypar (c) arch supports (Bridgens and Birchall, M, 2012)

A variety of tensile fabric systems can be used while developing the notion of tension fabric design. To create more intriguing and complicated designs, designed systems for anticlastic surface fabrics are integrated. According to Son (2007), the following systems exist: arch-supported structures, primary support structures, ridge-and-valley structures, and mast structures. These systems are explained in the following table (Table 1).

Table 1. Tensile Fabric System Types (Escrig and Sánchez-Sánchez, 2015)

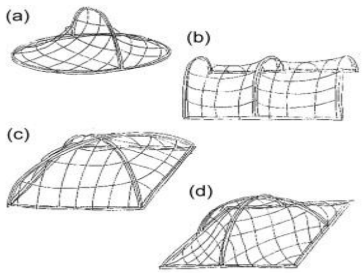
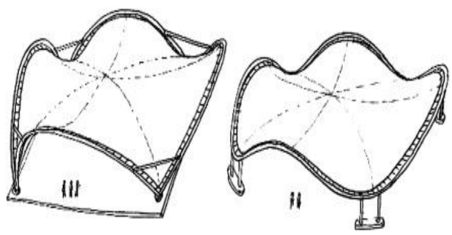
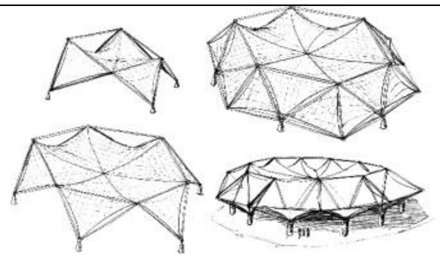
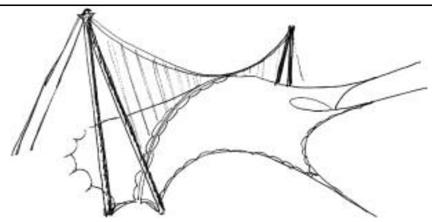
Membrane Types	System Examples
Arch-Supported Structures The membrane in arch-supported systems is in entire tension, whereas the arch should be in complete compression. The contact between the membrane and the arch, which results in the fabric's saddle curve, provides appropriate buckling resistance for shorter span arches.	
Structures with Primary Supports Saddle surfaces can also be formed in the membrane using primary point supports that, unlike the arch-supported system, do not lie on the same plane. The cable stays must be kept in tension regardless of the loading.	

Table 1. continued

Ridge-and-Valley Structures	
Ridge-and-valley constructions are designed to create a minor saddle by putting cables in an adjacent pattern with opposing curvature. The membrane is formed and supported by alternating ridge and valley cables.	
Mast Structures	
Fabric is suspended from cables strung off masts or other compression elements in tensioned fabric structures with masts as its supporting framework. This type of technology is perfect for long-span roofs.	

3. Materials and Method

This study demonstrates how the transcends typical tensile design concepts by utilizing new materials and inventive engineering. In this regard, the Khan Shatyr, a mega tensile structure, is critically examined in terms of architectural form, interaction with structural design.

3.1. Case Study- The Khan Shatyr

The Khan Shatyr ("Tent of the Khan") Entertainment Centre is one of the world's largest tensile constructions, and it offers a comfortable climate throughout the year. Foster and Partners designed the structure in 2006 as a huge transparent tent inspired by traditional nomadic construction forms (Foster + Partners, 2010). The massive edifice of Khan Shatyr incorporates a created icon of Kazakh nomadic history into Astana's architectural surroundings. The design concept is based on the traditional Kazakh yurt, emphasizing the importance of ethnicity in Kazakhstan's nation-building. Thus, the building in the shape of a traditional yurt awakens the Kazakh population's national memory; historical ideals of community are portrayed in a modern structure (Mkrtchyan 2013). In addition to producing symbolic strength with this massive structure, the design concept includes creating a strong iconic form on the skyline and designing a huge, free-spanning enclosure with minimal support (Dancey, 2010). The Khan Shatyr has a 200 m by 195 m circular base placed at the north end of the city's axis and is the highest point on the Astana skyline with its 150 m tall mast-stayed. The structure has 100,000 m² of internal space and includes an urban-scale park with a 450 m running track, shops, and leisure facilities like restaurants, cinema, wave swimming pools, and exhibition and event areas (Dancey, 2010).

The structural engineer for Khan Shatyr is Buro Happold. The structure is conceived as a tubular steel tripod mast that rises from the 195x200-meter elliptical base and supports the cable net in a conical shape. The tubular-steel tripod framework supports a suspended net of steel radial and circumferential wires, which is wrapped with a three-layer ETFE envelope constructed as 3.5 x 30-meter cushions - a lightweight, cost-effective, and thermally efficient solution. Fig. 2 shows the key structural pieces, tripod, cable net, and ETFE cushion.

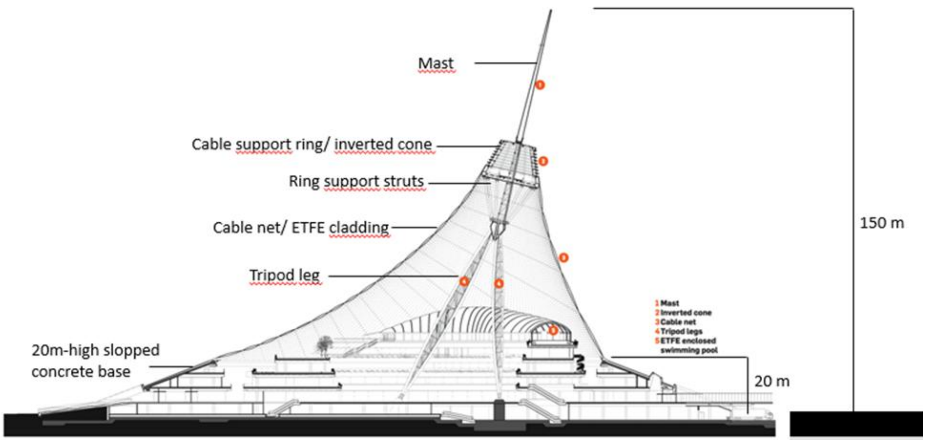


Fig. 2. Section through The Khan Shatyr shows structural elements of the building (URL-1)

The single-masted cable net is the obvious choice for providing such a massive, free-spanning enclosure with the least amount of support: a single compression mast elevates the cable net, creating a big volume beneath. The tensioned roof is constructed as a cable net, with cables being particularly effective load-carrying structural elements due to their efficient weight transfer via pure tension (Geyer et al., 2017).

The entire membrane structure is supported by a gigantic compression mast composed of three truss columns to withstand the massive compression force generated by the supported membrane structure. The steel tripod supports the entire cable net system. The basic premise behind its operation is to provide a single point of support to the core of the cable network. The roof skin is tensioned by a single compression mast, which lifts the net and creates a vast volume beneath. The entire mast (Fig. 3), including the tip, stands 150 metres tall and weighs around 2.500 tons of steel. The tripod is made up of one vertical rear leg that is 60 meters tall and two spread front legs that are 70 meters long. Legs are built of triangular tubular steel trusses grouped into three-chord trusses with 1000 mm diameter round hollow sections made of 40-millimeter-thick tin. The three-legged mast creates a sturdy ring in the air that the cables may be attached to on-site. A single mast was deemed too challenging to handle on-site at this vast scale. The mast's legs meet at a 7-meter-high hub made of 150-millimeter-thick steel plate; the hub center line corresponds to the axis of the cable net's axial force under prestress. A hub holds 12 pin ended struts of 800 mm diameter that reach the cable net's top ring. A 20-meter-diameter top ring is fixed. This is formed from a circular portion of 1.6m diameter and 40mm thick; its job is to gather the cables together (Numanova et al., 2020).

Building a massive cable net structure is thought to be the most efficient and cost-effective solution to cover such a big area because it only requires one central column, which is then surrounded by a giant roof. The cable net is shaped like a classic cone that has been pulled to one side. This creates the Entertainment Centre's characteristic sloping architectural form. The cable net consists of 192 radial cables and 16 circumferential cables (Birch 2009). To enhance handling, cable diameters were kept below 76mm, and cables are typically put in pairs to provide strength, which also simplifies clamping between radial and circumferential cables. Radial wires connect the top ring to the concrete plinth around the circumference. These support both the roof weight and the weight of any snow, which is significant in Kazakhstan's winters. The circumferential cables are used to stabilize the radial ones by pulling against them, as well as to confine the roof against wind stresses. Fig. 4 depicts 192 pairs of 38mm diameter radial wires that range in length from 125m at the tent's front to 70m at the back.

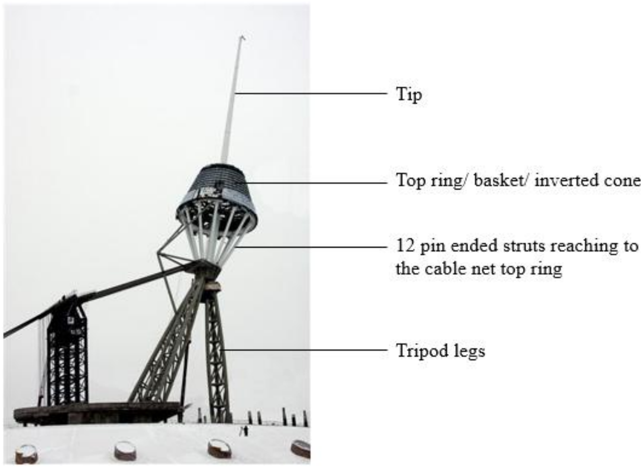


Fig. 3. Whole mast structure of the Khan Shatyr (Geyer et al., 2017)

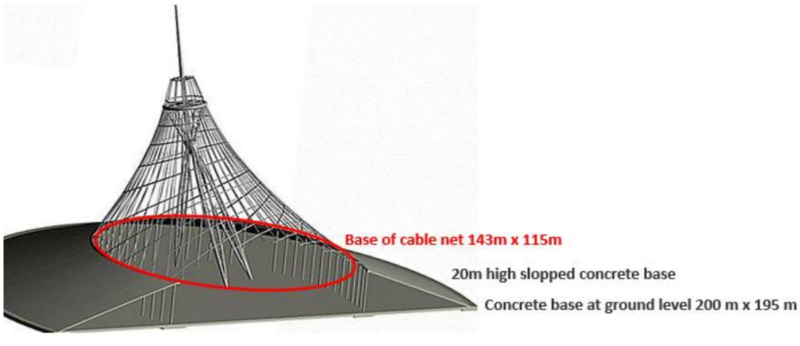


Fig. 4. The roof’s cable net, attached to the basket and concrete base (URL-2)

4. Conclusions

The Khan Shatyr, like most preferred tensile buildings since the 1960s, is supported by a mast, which acts as a compression element. The constructions often have a tensile membrane consisting of ETFE cushions, with bigger schemes necessitating cable netting for additional support. Their lightweight and cost-effective construction makes them perfect for covering vast areas like as exposition venues and sports stadiums. The Khan Shatyr's form-finding research began with standard hanging models to determine the overall behavior and contour of the cable net. The inclined cone shape was selected, and computer models were created to determine the overall shape and cable arrangements. The central support pole is meant to function as a solid tripod, allowing the net to move under various stresses. The ETFE cladding on the cable net maximizes the transparency that this type of construction enables, eliminating the need for a smaller glazing grid and making it flexible enough to withstand the rather large predicted movement of this tensile structure (Mangelsdorf, 2010). As a result, structurally optimum alternatives were identified. However, from an architectural standpoint, it is difficult to answer the questions of whether the Khan Shatyr is a modern building, whether the final form of the Khan Shatyr, which resembles a primitive tent, is the optimal form, and whether learning from or referring to history is the same as imitating it. To summarize, the Khan Shatyr's structural design accomplishment resulted in a rudimentary tent form on a massive scale. In the 2000s, a millennium structure, a landmark building in Astana, was constructed by directly scaling a traditional tent rather than exploring new designs.

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In the context of urban memory studies: The relationship between boulevard and architecture (Ankara Apartments)

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Abstract. Memory interacts with space and time, establishing a sustainable relationship between the past and the future. This relationship, which is equally relevant for cities, emerges from the strong interplay between urban memory, space, time, and urban identity. The spatial and sociological transformations experienced by a city influence its urban memory, and consequently, the urban dwellers who are the primary actors of urban life.
The aim of this study is to analyze the relationship between collective memory and the city through the apartment buildings located on Atatürk Boulevard and its surrounding capillaries in Ankara, and to highlight the significance of civil architecture in shaping memory. As a first step, the study examines the relationship between Atatürk Boulevard and memory. The formation, development, and transformation of Atatürk Boulevard are analyzed within the context of the historical periods it has witnessed, focusing on its connection to the city through the buildings and functions present along the boulevard. In the second stage, the study explores the changes in daily life on the boulevard and investigates the role of civil architectural memory, represented by apartment buildings, as the spatial context of this life. By examining the architectural features of these buildings, the study discusses the impact of civil architecture on collective memory.

Keywords: Urban Identity; Urban Memory; Civil Architecture; Ankara Apartments; Atatürk Boulevard.

1. Introduction

Identity can be defined as "the totality of signs, qualities, and characteristics of a social entity" (Turkish Language Association, 30 July 2024). From this perspective, urban identity can be defined as a concept that distinguishes cities, which are –complex social entities–from others and defines their unique qualities.

The components of urban identity, interpreted through human perception, serve as an important link for cities to sustain their existence from the past to the present. Urban identity is shaped by the social traces and impressions left by the spatial and social elements that constitute the city on its users. Topçu, drawing on the definitions of Lynch, Tekeli, and Çöl, describes urban identity as a comprehensive set of meanings that is constantly shaped, changed, and transformed by the lifestyles of the society in which it exists, formed by the interpretation of physical, cultural, social, economic, historical, and formal factors in different parameters, and extending from the past to the future (Topçu, 2011). Urban identity is an organic structure shaped by all the physical, social, and cultural dynamics that belong to and influence a city (Köseoğlu, 1995).

The city itself can become the subject of collective memory, and the change and transformation of each building block that shaping the city, – along with the social, spatial and societal events–- directly influence collective memory and, consequently, humans. In this context, the study examines the relationship between Ankara — the capital of the Republic of Turkey and one of the leading cities in the development of the country's urban identity, which has undergone rapid transformation since the beginning of the 20th century— and Atatürk Boulevard, an important part of the city's memory, within the framework of collective memory.

Urban memory encompasses all values associated with a city and its inhabitants. All elements of life within a city have the potential to serve as building blocks of urban memory. When examining Ankara, Atatürk Boulevard holds great significance for the city's urban memory. The morphological and sociological changes that the city has undergone can be easily read through the boulevard, making Atatürk Boulevard a place of memory for the city. As a result of the spatial developments the city has undergone, the boulevard has undergone physical and sociological changes, and these changes have shaped the design criteria of the structures on the boulevard, transforming the living conditions, functions, habits of the community, and the flow of daily life, and thus affecting

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collective memory. These collective memory readings are primarily realized through public spaces and structures that maintain a strong presence and a more distinct continuity along the boulevard. It is observed that the impact of civil architecture, – a significant part of the city's daily life shaped by social components– has been pushed into the background. At this stage, the aim of the study is to examine the multifaceted impact of the transformation of Atatürk Boulevard, which was influenced by planning efforts to create a modern capital city for Ankara, on collective memory, and to ensure that the importance of civil architecture, whose impact is considered to have been overlooked, is understood in light of the lasting impact of public structures on memory.

Collective memory is shaped by the interaction between space and time on an urban scale. Atatürk Boulevard is a place of memory that reflects morphological and sociological transformations specific to Ankara. The aim of this study is to explain the impact of civil architectural memory on urban memory through apartment examples on Atatürk Boulevard and its capillaries from a holistic perspective. At this stage, the development of the boulevard was examined with the help of relevant literature, and comparative architectural analysis methods were integrated based on selected examples.

2. Conceptual Framework

2.1. City, Identity, Memory- Urban Memory and Collective Identity

Cities acquire their identity through the effects and interactions of their surroundings over the course of historical development. The identity of a city is shaped by the relationships and interactions between the natural, social and built environments, which distinguish it from other cities. Urban identity is jointly produced by the cultural structure — rooted in natural environmental conditions and the social environment— and the built environment. Identity based on the built environment is shaped by the spatial structure which forms a cohesive whole through its form, location, type of use, and meanings. This situation is particularly evident in Turkey, where the diversity of cultures and the environmental data of the various natural, social, and built environments in cities contribute to a multi-dimensional and distinctive identity (Suher et al., 2004).

The concept of spatial memory acquires meaning by combining concrete data related to space with individual, social, historical, and cultural values existing in the individual's mind. This comprehensive entity is nourished not only by representations, signs, and symbols, but also by parameters such as social, political, architectural, and cultural events, traditions, habits, and neighbourly relations of its time (Avcıoğlu & Akın, 2017). The city, which is the subject of collective memory, and the parameters of the city, as well as the social and spatial changes that affect the city, influence collective memory and, consequently, its inhabitants. The fact that capitals are at the center of developments that shape the history of countries makes them symbolic cities in terms of cultural, political, economic and social issues experienced in the historical process. In the continuation of this study, the city-memory relationship will be examined within the framework of collective memory, focusing on the missions assigned to Ankara, the capital of the Republic of Turkey, as a capital city.

2.2 The Role of Boulevards in Urban Fabric

Lefebvre (1991) describes urban spaces as not merely physical areas, they are socially produced spaces for everyday life. Cities, as spaces inhabited by people, are dynamic formations where social, cultural, and economic balances are established.

Boulevards within cities serve as multi-layered axes that form the physical and spatial backbone of the city, connecting different functions and different times within the city and establishing a link between these spaces. These axes, where social interaction, transportation, circulation, and cultural representation occur simultaneously, play a crucial role in shaping the urban fabric. In urban design, boulevards, when considered together with the public spaces, residential areas, parks, squares, and socio-cultural spaces, serve as the main arteries that directly influence and shape daily life within the city. These areas also function as public realms that contribute to the collective memory of cities and where residents' memories of place are formed (Hayden, 1995; Rossi, 1982). From this perspective, the memories that city dwellers create within this backbone and the connected spaces form an emotional and historical bond with the city, fostering a sense of belonging to the city and internalizing the city's identity. The bonds that individuals first establish within themselves evolve into the production of a social memory as a result of their interactions with one another.

In conclusion, boulevards are not merely physical arteries; they are urban elements that play a role in shaping both the social and physical fabric of a city as urban backbones where different socio-cultural interactions take place, social memory is produced, and spatial continuity is ensured. From this perspective, Ankara Atatürk Boulevard serves as a notable example illustrating the effects of boulevards. According to Bozdoğan (2001), Atatürk Boulevard connects the old and new parts of the city along the main north-south axis of prestige. In this situation, it is possible to read both the effects of building a new city in terms of urban design and the traces of producing a new society ideologically through a capital city via Atatürk Boulevard.

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2.3 Architecture as a Reflection of Urban Memory

Architecture, as the producer of space, is a potent reflection of social memory. To understand this relationship, we must first examine the relationship between space and memory, and then examine the impact of this relationship on an urban scale. While space can be defined in various ways, the prevailing view is that it isn't simply a physical concept, but rather a conceptual entity that derives its meaning from its connection with society. According to Al, space is a conceptual plane that is linked to belonging and identity and contains social connections (Al, 2011). Lefebvre (1991) describes space as a social product and explains the mutual relationship between space and society. Consequently, space, which affects humans, and humans, who produce space, are described as two phenomena that can't be evaluated independently of each other. According to Aytaç, space is an entity that parallels the mental world of its users, provides a common ground for social experiences, and, through its social meanings, reconstructs the people within it and provides them with a sense of belonging (Aytaç, 2013). In this sense, urban spaces are existential islands for urban dwellers. With their openness to daily routines, they are a kind of identity space. Space, with its different meanings, is a reference point for perceiving the city, people, and society. When the interaction between space and individuals is expanded to a larger scale, it evolves into an interaction between urban inhabitants and urban spaces. Within this relationship, people come together with their individual identities and form a collective identity. Architecture plays a pivotal role in shaping this identity and producing collective memory through urban spaces.

Urban spaces, as both reflectors and generators of collective memory, assume a symbolic and critical role in preserving the continuity of memory. They provide temporal continuity in the relationship between the past and the future for the city (Aytaç, 2007; Çalak, 2012). When examining cities, the ultimate subject of the space-urban space-city relationship, we observe living formations where socio-cultural, political, and economic dynamics are spatialized and memory is layered. According to Rossi (1982), the city itself is the collective memory of those who live there. Every piece of the city contains the city itself and its memory. Written and oral disciplines are insufficient for the transmission of this collective memory. In this context, architecture takes on a critical role as a means of transmission. The subject of this study is Atatürk Boulevard, which was designed to serve as a link between the existing city and the capital city that was intended to be built in in accordance with the ideology of the Republic. This design isn't merely a physical link, but rather an example of a memory space that reflects many various processes, such as the modernization process, the effects of ideological dynamics on the city, and the social effects of the construction of a new city. At this stage, civil architectural buildings located on Atatürk Boulevard and its capillaries, which are most experienced by city dwellers and therefore critical for urban memory, will be examined within this conceptual framework.

3. Collective Memory Reading on Ankara

Capitals are symbolic settlements that reflect the morphological and sociological experiences of countries. Ankara has become the symbolic city of the transformation that the country underwent with the proclamation of the Republic. Ankara, which has been at the forefront of the country's modernization process, has witnessed this process of change and transformation in various fields such as industry, social life, culture, education, architecture, and art. With Ankara becoming the capital, urban planning activities in the city were also regulated. With the development of industry, the city experienced intense migration between 1923 and 1950, leading to the establishment of housing policies specific to Ankara for the first time in Turkey and the allocation of resources for housing. During this period, individual housing production was replaced by collective housing projects and cooperatives (İrdem & Lenger, 2021).

1924 marked the beginning of planning efforts for Ankara began. The plan developed by Lörcher for the castle and old Ankara was deemed unrealistic and was therefore never implemented. In 1925, the Lörcher Plan, which covered Kızılay and its surroundings, laid down fundamental decisions regarding this area (Özkan, 2018). Although the Lörcher Plan was not fully implemented, it is regarded as having played a decisive role in in the city's development, both in terms of creating a strong boulevard axis connecting the nation's symbolic structures and in terms of design ideas aimed at integrating the old and new parts of the city (Uluiş, 2009).

Due to the city's rapid growth beyond what was anticipated in the Lörcher Plan, an international competition was organized, and Hermann Jansen's proposal was accepted (Özkan, 2018). It is considered that the Jansen Plan, with the opportunities it offers city dwellers to encounter the natural and built environment, reinforces their sense of urbanity and belonging. The most prominent feature of this process is the development of housing projects of varying scales and types (Güneri Söğüt & Baş Bütüner, 2023). The Yücel-Uybadın Plan, whose effects are most evident on Atatürk Boulevard, has led to an increase in urbanization due to the design of buildings and parcels around Kızılay (Günay, 2005). With the changes that cities undergo, city centers gradually lose their functions but strive to maintain their relevance. These areas continue to evolve, maintaining their central role in urban life. For this reason, city centers can maintain their use value when they have spaces that preserve their specific activities (Lefebvre, 2015). In this context, Ankara Atatürk Boulevard has established a strong urban backbone in the city's memory by creating a significant axis for the city and incorporating various functional dynamics that have changed and transformed over time.

3.1 Spatial Structure of Atatürk Boulevard

If Atatürk Boulevard is considered an axis of memory, there are points where it feeds off and comes into contact with different periods and different representations. These points can form a mental map in the memory of the city's inhabitants. In the case of Ankara, it is important to examine what the boulevard signifies for its inhabitants and to trace the memory remnants that have survived and those that have not reached the present day. Cengizkan (2024) summarizes the boulevard's multi-layered and multi-functional structure through nodes. The points referred to as nodes represent the parts of the city that define its identity and leave historical traces.

According to Cengizkan (2024), the first node is the part between Ulus and Opera Square. Ulus, where the boulevard begins, was considered the economic and political center of Ankara at that time. The section starting from the Ulus neighborhood, shaped by Lörcher's plan in 1924, and extending to Opera Square can be considered the starting point of the boulevard's collective memory. This section, where foreign embassies were located, gradually came to be known as “Bankers' Street.” In this node, public institutions and banks, which were the spatial counterparts of development initiatives that were prioritized for a country undergoing a political revolution and emerging from war, were established**.**

The second node is the area between Opera Square and Sıhhiye Square. In this node, the spatial counterparts of cultural development movements, which are the next step in the effort to create a modernist capital, can be seen. The cultural gaps created in society by a collapsing state were addressed, and steps were taken to support future generations in these areas. A cultural axis consisting of institutions of critical importance to society was designed and completed with a park dedicated to youth.

The third node, known as the central area of Atatürk Boulevard, is the section between Sıhhiye Square and Kızılay. Cengizkan (2024) describes this area as the most prestigious section of the boulevard. In contrast to the low-rise buildings of the new city, high-rise buildings overlook the tree-lined boulevard. Modernist lifestyle functions such as shops, cafes, bars, and cinemas are located here in their most prestigious manifestations. With this node, more specialized living standards have become part of the new capital's characteristics. Prestige has become a key feature of the modern capital and is beginning to shape the daily lives of its residents. This node serves as the focal point of both daily life and memory.

The fourth node begins at Kızılay-Güvenpark and continues to Akay Hill. This node is home to ministries and government agencies, hence its designation as Bakanlıklar-Akay (Ministries-Akay). Cengizkan (2024) emphasizes that the eastern sidewalk defines the character of this section. With the acceleration of apartment construction, embassies have been replaced by large stores, well-known pastry shops, and global brand representatives. Government institutions such as ministries have been included in this section to reinforce the prestige image designed for the third section. This node represents the prestige of the new state through a modern axis.

The fifth node covers the area between Akay and Kuğulupark. This area is largely home to embassies and symbolic structures of Ankara. Cengizkan (2024) describes this node as the most diplomatic area of Atatürk Boulevard. On the western side are foreign embassies and TRT, while on the eastern side are symbolic structures and important institutions of the new state. This is the node where diplomacy reigns and the memory of global connections is represented. The cultural interactions resulting from the embassies have also influenced the design of civil architectural structures. The sixth node is the Protocol Road that starts from Kavaklıdere and extends to the Presidential Palace.

Cengizkan (2024) dedicates the final node to Atatürk. A symbolic conclusion is reached, Culminating Mustafa Kemal Atatürk, the architect of all this transformation and after whom the boulevard is named. With this node, the boulevard conveys all the memories and representations it has brought with it to the true owner of this transformation.

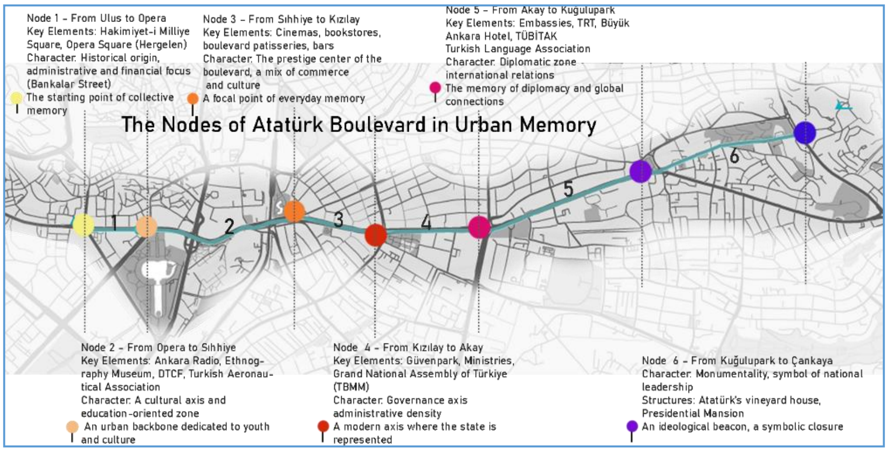

Fig. 1. The Nodes of the Boulevard. (Prepared by Çağla Canca.)

3.2 Atatürk Boulevard and Urban Memory

From the construction of the capital to the present day, Atatürk Boulevard connects Ankara's symbolic structures and the institutions that keep them alive, as well as the city's diverse urban spaces of varying scales and qualities where daily life continues. Over time, the boulevard, which extends from north to south and unites the city's districts, has acquired the function of a corridor that brings together the unique rhythms of different periods. From this perspective, Atatürk Boulevard can be considered a medium that preserves traces of Ankara's spatial change and transformation process, as well as a structural interface that records the social memory of the Republic of Turkey from its founding to the present day. With the 2000s, the increasing tendency to demolish and rebuild in urban space production, changing in form and scale, has affected the perception of memory. Understanding how this perception has been affected, how the traces recorded in space have been transferred to the present, and what their potential for the future is important for the sustainability of memory. With this quality, Atatürk Boulevard and its surroundings function as a laboratory (Birik, 2024). As explained in the previous section of this study, the boulevard tells the story of Ankara's transformation into the modern capital of a modern nation through numerous spatial traces and reflections, similar to a timeline. The boulevard and the collective memory it created have been largely destroyed, as has the rest of the city. This destruction can be attributed to many factors, including urbanization problems and misguided urban planning strategies, ideological and political reasons, population growth, and changing lifestyles (Fig. 2).

It is well known that many of the symbolic structures of the period, such as the qualified and even registered İller Bank, Danıştay Building, and Etibank General Directorate building, which were designed through competitions, have been demolished on the boulevard. The continuous demolition of structures on this axis and the alteration of the boulevard's silhouette are causing the loss of memory. Additionally, the deformation of the traffic route connecting the Opera and Çankaya districts through different road and route alternatives has been observed to disrupt the continuity of the boulevard's user experience and influence the city dwellers' perception of the boulevard (Cengizkan, 2012) (Fig. 3). In conclusion, it is believed that all the destruction and demolition that has taken place have led to the significant loss of the collective memory formed by Atatürk Boulevard which has witnessed every phase of the efforts to establish the new capital of the new republic and has been shaped by these phases, serving as a memory space in its own right for the city.

When examining the boulevard in the 2000s, it is evident that there are no traces of the high-quality buildings, squares designed with social life in mind, developments made for the sake of an ideology, or structures and spaces produced with design concerns that were present during that period. As a result, the Boulevard, which once served as a representation of memory, has evolved into a void within the city's collective memory, with information about it now accessible only through written and visual documents specific to the Boulevard. While the relationship between the public structures and spaces on the Boulevard and memory can be questioned through these documents, there is insufficient information and a lack of a network of connections regarding civil architectural elements. Following this section of the study, the relationship between civil architectural structures and life on the Boulevard will be examined, and civil architectural memory will be questioned.

4. Atatürk Boulevard and Civil Architectural Memory

Ankara's urban image has always referred to the state (Bayraktar, 2014). The city's status as a capital, the way ideologies express themselves through architecture, and the dominance of public structures have caused memory to be read solely through public structures. However, residential structures create a memory space that reflects the political, cultural, and socioeconomic data of the period by establishing closer contact with everyday life. Memory readings through civil architecture offer more layered data.

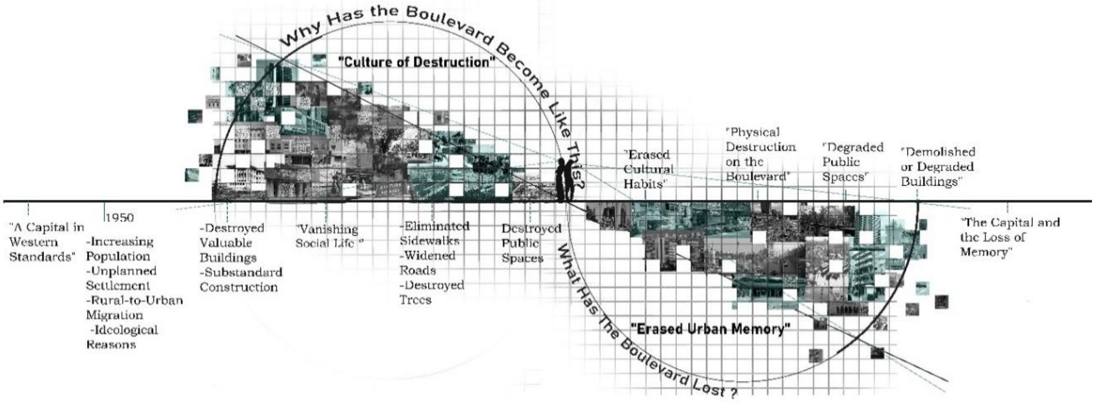

Fig. 2. Destruction of the boulevard. (Prepared by Çağla Canca.)

Fig. 3. The effect of demolition on the boulevard. (Prepared by Çağla Canca.)

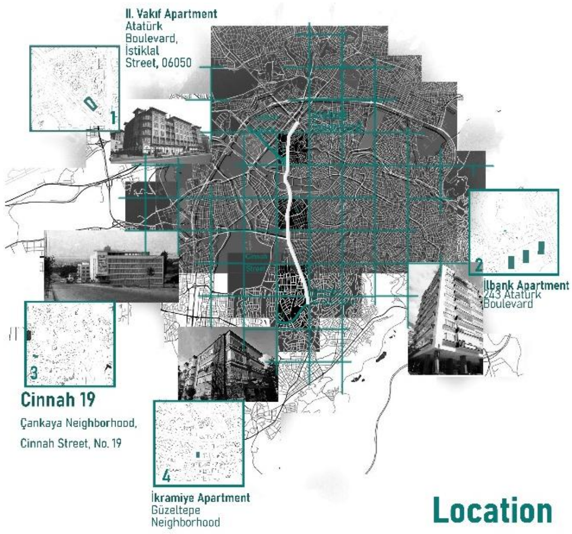

Fig. 4. Locations of the examined structures. (Prepared by Çağla Canca.)

In a new and modern urban development process, housing design criteria established according to planned and idealized social conditions have become a phenomenon that bears the traces of the era. The initiatives undertaken by the new republican regime during this period transformed the daily lives of the city's residents and profoundly reshaped housing production. From the location of housing within the city to its interior spaces, from the social character of neighborhoods to their physical, technical, and spatial characteristics, housing production in Ankara in the 1920s was determined by the contextual characteristics of the newly established Republic (Avcı Hosanlı, 2018). For this reason, comprehensive readings about the dynamics of the period can be made through these structures. At this stage, it is of great importance to create a civil memory in contrast to public memory through residential buildings. In this study, architectural-scale examinations of apartment buildings were conducted within the scope of civil architectural memory. Considering the importance of everyday life for urban memory, the impact of residential buildings, which are the spatial settings of everyday life, on the collective memory of the city cannot be denied.

Within the scope of this study, these traces were examined through the apartment buildings located on Atatürk Boulevard and the side streets feeding into it. In this context, İlbank Blocks, Cinnah 19, II. Vakıf Apartment, and İş Bank İkramiye Apartment, which met the housing needs of their time with different arrangements and are important in terms of memory spaces, were examined (Fig. 4.)

4.1 İlbank Blocks (İlbank Housing Cooperative)

The İlbank Blocks, Ankara's first housing cooperative, designed by architect Fatih Uran in 1957, are located between Iran Avenue and Atatürk Boulevard It is thought that the ideology of Unité d'Habitation, which also influenced other buildings of the period, lies at the basis of the design idea. The building's resemblance to *Unité d'Habitation*, which is thought to have been influenced by its structural features, reflects the aspiration to organize collective life. With this characteristic, it can be interpreted as a pioneering example among co-operative buildings of the period (Fig. 5).

At this point, it should be underlined that these co-operative buildings, similar to the Unité d'Habitation, almost all of them stand on pilotis, have a flat roof and feature common spaces where the residents can socialize both on the ground level and on the roof-terrace floor (Şumnu, 2018).

Şumnu (2018) states that this situation in the buildings of this period is at least as important as the interiors of the flats, emphasizes that the emerging approach focuses on communal integrity rather than isolation, and highlights the attempt to glorify the sense of 'we' beyond 'I' in residential buildings, and that these buildings, most of which are facing the danger of demolition today, are important examples of civil architecture that should be preserved not only for the architectural style decisions they embody, but also for the culture of communal life they represent.

İlbank blocks consist of 3 buildings, two of which have 8 floors and one of which has 9 floors. The blocks feature two basement floors and a two-story-high pilotis at ground level, above which they rise to eight or nine floors. The façades are based on a pattern formed by the protrusion and retraction of symmetrical balconies. The horizontal effect of the facade is strengthened with balcony parapets. In addition to the common/social spaces offered between the blocks in the settlement, common/social spaces are also designed within each apartment block. In the original projects, the ground floors of the blocks were left open to a height of two stories, and access to the upper floors was provided by passing through this space. Today, the ground floor spaces of the blocks (except for Block B) have been enclosed and reserved for commercial uses. Similar to the ground floor, the roof terraces is also considered as a common areas that can be used by the residents. In the projects, large open spaces on the roof terraces are supported by several service facilities (e.g., WC, kitchen, etc.) (Şumnu, 2018). By raising the blocks with pilotis, it is possible to maintain a continuous open space pattern that extends between the two boulevards on the ground and connects the boulevards, fed by closed public spaces that partially fill the ground floors of the blocks (Varol & Elibol, 2021). This has enabled the buildings to maintain interaction with Atatürk Boulevard.

The floor plans of the blocks consist of three flats located around two circulation cores. Two blocks are placed side by side to form a single block with two entrances. The four symmetrical flats located at the corners are entered from a large vestibule, which opens to a lounge-dining room and kitchen. The bedrooms, toilet and bathroom are reached through a corridor passing through the living room-dining room area. Detail solutions, such as niches created for storage on the balconies reveal the quality of the design. A similar design is seen in the symmetrical flats with two facades in the center. These flats are also entered through a vestibule opening to the lounge-dining room and kitchen, and this time a corridor leading from the vestibule leads to the toilet, bathroom and bedrooms. The wet areas of all apartments are ventilated by means of light wells, two of which are located in the circulation core and one in the center (VEKAM, 2014) (Fig. 5).

Modernization efforts have transformed daily life and, consequently, residential spaces. In İlbank Blocks, this transformation is seen in details that are not found in traditional Turkish houses such as garbage chutes descending from the kitchen to the basement, service windows between the kitchen and dining area, and storage niches on the balconies. The İlbank Blocks are considered an important and unique settlement with both the design approach and the vital facilities offered the users. Çapanoğlu (2007) states that in addition to its modernist elements, it was the most comfortable and tallest building in Ankara at that time with its site plan layout and neighbourhood relations. Many of the elaborate details used during the period and creating a prestige in the choice of housing have not survived to the present day.

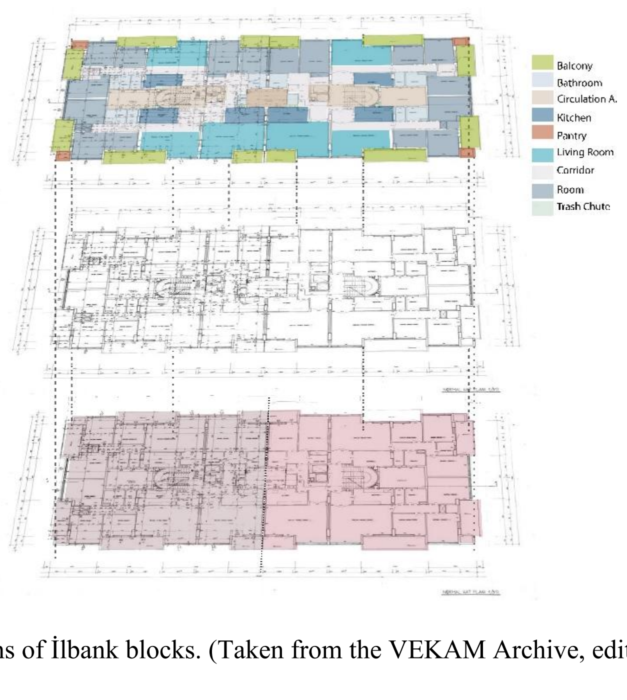

Fig. 5. Floor plans of İlbank blocks. (Taken from the VEKAM Archive, edited by Çağla Canca.)

4.2 Cinnah 19

Cinnah 19, designed by Nejat Ersin in 1955, is a building constructed with the housing incentive of the Real Estate Credit Bank of Turkey, founded by the employees of the Meydanlar Directorate Workers' Building Cooperative Partnership. It stands as one of the important examples of cooperative-based housing production from the period.

Ali Cengizkan summarises the architectural features of the building as follows: "The building is a highly contemporary product of the period in which it was planned and built. The reference to the 'Unit d'Habitation' block in Marseille, which is an important example of the 'modern' living and residential environments brought to architecture by the French architect Le Corbusier, the similarities, fidelity and the dimensions of their adaptation to the situation as original principled design elements are important: Emptying the ground and leaving the topography in its natural state; the democratization of the housing units by means of the duplex plan design, allowing them to benefit equally from all the blessings, while doing justice to the qualitative differences of the place; due to the importance attached to the collective way of life, to living together in a community as a culture, the proposal of a common garden on the ground, common coal cellars and storerooms, sheltered seating and a common stony area for sports; the provision of a framework where each unit, like a beehive, first establishes its own particular world and then opens to the upper world; elevated streets where passive encounter opportunities are created and swimming pool proposals on the terrace floor. All these have been reinforced by the use of the given right of construction as a design input in a way that does not disturb the location features of the environment such as landscape and slope and further emphasizes them, and by reflecting them on other architectural decisions such as interior furnishing, for example, a residential environment where contemporary values are emphasized has been obtained. (Cengizkan, 2002).The building was constructed as a reinforced concrete frame and brick infill system, with two basement floors below the road level, three normal floors consisting of duplex housing units above the road level and a terrace floor with a swimming pool (VEKAM,2014).

In the original project, the building was detached from the ground, the topography was invited within the building and a common living area was created here, but with the caretaker's apartment built later, this area was partially enclosed and to some extent, rendered dysfunctional. On the terrace floor there was a pool, American Bar, fireplace, shower, changing rooms and toilet. This part was used for about ten years and was closed due to concerns over the spread of polio that emerged there during the period.

The public spaces provided on the terraces and ground floors of the building are balanced with the calmness, quietness and even individuality of the private spaces provided on the residential unit floors. Since the corridor common spaces on the floors face south, the façade is given a very uniform and ornamental appearance with sun shades, and this harmony is enhanced by covering the corridor floor finish with black and white mosaic. Here, the discourse of modern architecture establishes a relationship with industrialized construction materials and artisanal construction techniques, which is a symbol of the search for freedom in the discourse of the 1950s in the field of "overly disciplined" architecture and is a very common attitude (Cengizkan, 2002). The first flat on the first basement floor is entered through a small vestibule opening to the kitchen, which leads to the dining area with an American bar and then to the living area. A corridor leading to the vestibule leads to the wet rooms, the maid's room and the bedroom, and the dressing room, which also opens to the corridor, leads to the bedrooms. In the second apartment, the vestibule is separated from the dining room and the living room with a fireplace by a wooden partition. A long corridor from the vestibule leads to the kitchen, maid's room and guest room, and a second corridor leading to the corridor leads to the dressing room associated with the nanny-child room and the bathroom (Fig. 6).

Fig. 6. Floor plans of Cinnah 19. (Taken from the VEKAM Archive, edited by the Çağla Canca.)

The duplex housing units are similarly accessed through an entrance hall, which opens to the kitchen and the Similar to the duplex housing units, the entrance is through the vestibule, which opens to the kitchen and the maid's room. Beyond the dining area which is connected to the toilet, library and kitchen through a small space, lies a lounge with an open staircase providing access to the upper floor. The hall on the upper floor, accessed via the staircase, is connected to the living room through the gallery space, and the hall is followed by the bathroom and bedrooms. The library also leads to the bathroom and bedrooms on the upper floor. Cinnah 19 is a unique and distinctive building with its relationship with the topography, design decisions, use of common space within the building, detail solutions, dynamic façade layout (VEKAM,2014) ((Fig. 6).

As a plan type, the duplex apartment targets a young, dynamic family type: Perhaps it is very appropriate in terms of timing to introduce private spaces on the floor planes for families who had to gradually detach themselves from the land in the overcrowded cities during the 1950s. Despite all the influences and inspirations, there is an "internalized modern attitude" here (Cengizkan, 2002).

4.3 Vakıf Apartment (Evkaf Apartment)

2.Vakıf Apartment is a building located on the boulevard, the design of which was started in 1927 by Architect Kemaleddin Bey and completed in 1930. During the period, there was a housing problem in the city with the increasing population. At this stage, it is known that the General Directorate of Foundations constructed the building to provide income through rent and to offer accommodation for its officers.

The building consists of seven floors: a basement, a ground floor, four residential floors, and a roof floor. On the outer perimeter of the ground floor, there are shops and a coffee house. In the courtyard in the central courtyard of the ground floor, there is a theatre hall that is still used as a theatre today. Until the 1940s, due to political reasons and the fact that theatre had not yet established itself in the city, this area was used for various purposes. Since the 1940s, it has operated as a state theatre under the name 'Küçük Tiyatro.' There are four different entrances on the ground floor of the building. The elevators at each entrance were considered quite luxurious for their time. These elevators are still operational within the building. The four entrances are currently used as the audience entrance, actor entrance, protocol entrance, and staff entrance (Fig. 7).

On the first floor of the building, the theatre hall continues in the central section, while apartments, offices, and a billiard hall are located on the façade. Along with the other three residential floors, there are a total of 40 apartments on the perimeter and 12 shops on the ground floor. In 1957, some of the shops on the ground floor were gradually merged to create a theatre hall. This development elevated the building to an important position in the theatre world and ensured cultural continuity within the space. In support of this initiative, Turkey's first theatre specialized library was opened within the building in 2011.

When examining the façade features, the long façades have a central section with five axes and two axes on each side, while the narrow façades have a central balcony section with single-axis side sections that extended outward and raised, covered with wide eaves. This design aims to achieve the massing form characteristic of the first national architectural period. The rounded lines of the balconies and railings at the four corners of the building, the mostly square-shaped windows without arches, and the minimal decoration are features that distinguish the building from the national style and reflect the rational-modernist approach of the period. The area where ornamentation is concentrated is the theatre hall, topped by an oval dome. The use of arches is limited to the half-circular arches connecting the evenly spaced columns on the ground floor. The reinforced concrete structure is covered with plaster, giving it the appearance of neatly cut stone from the outside. (Yazman, 2013). The building has been used for purposes other than residential use. In addition to being used as a theatre and library, it has also served as the Faculty of Language, History and Geography, the MIT building, and later as the General Directorate of State Theatres. The building has been used for functions such as residential, storage, theatre hall, and government office, and has also had a diplomatic role in the past.

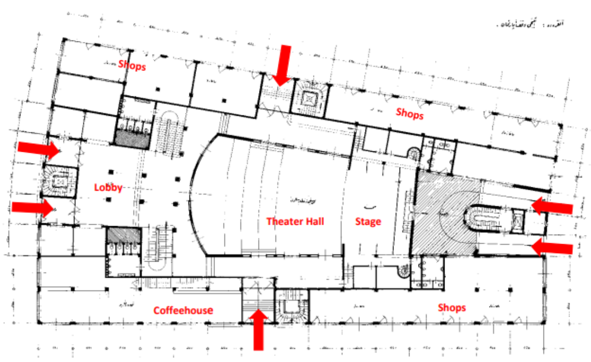

Fig. 7. Ground floor plan of the building (Originally from the Archive of the General Directorate of Foundations, adapted by Yalçın & Kula, as cited in Yalçın & Kula, 2024, p. 438).

In 1930, it was used as the Romanian Military Attaché's Office. The Evkaf Apartment stands out from other residential buildings due to its cultural activities, its combination of residential, office, and shop features, its inclusion of an elevator—a novelty of the time—and its role as a semi-permeable barrier between the city and its inhabitants. Additionally, it stands out as an example that reflects the spatial aspects of modernism through its innovative features.

4.4 İkramiye Apartments – İş Bank Apartments

İş Bank Apartments is a lottery housing complex designed by architect Lemi Varnalı in 1968, consisting of eight apartment buildings connected to each other by gardens. Each apartment building has five floors, comprising a basement, a ground floor, and three upper floors. Lottery apartment buildings, constructed on a limited scale in the 1950s under the influence of centralized state governance and global development models, evolved into a significant sector after the 1950s due to the impact of liberalism and the involvement of private banks. Banks not only provided financial support but also encouraged homeownership through advertising and lotteries. Through their housing projects shaped according to their own ideologies, they contributed to the diversification of civil architecture.

These apartment buildings, which are the latest example of İş Bank's lottery housing project in Ankara, are connected to each other by large communal gardens. In addition to the relationship established with greenery, the pools located at the entrance of the apartment building and on the floor of the basement overlooking the gallery space, as well as the gallery space that allows light to enter the building throughout the day, indicate the careful relationship established between the building and nature. This relationship with the surroundings continues in the apartments. Compared to the square meters of the enclosed spaces, each apartment has large semi-open balconies. These balconies, located in both the living rooms and bedrooms, not only connect the apartments to their surroundings but also to each other. This relationship between the apartments continues in the building's floor lobbies. These shared spaces, rich in architectural detail, are designed to facilitate communication between apartments on the same floor as well as those on different floors (Şumnu, 2014).

The pools at the entrance of the building serve as a threshold between the building and the exterior space. The entrance of the building is designed to be transparent, allowing the building to be easily viewed from the outside and showcasing the carefully designed interior space. Upon entering the building, one encounters a vertical circulation space that can also be described as an inner courtyard, which receives light throughout the day thanks to the skylight above it. This space, which is one of the building's distinctive features, has the potential to be used as a common area by the building's residents. Three apartments of different sizes are located around this area, with a fixed number of rooms. Access to the apartments is provided through an open space connected to the living room and kitchen, which leads to the entrance hall. The fireplaces located in the corners of the living rooms are the most striking feature of the apartments and create a different perception on the façade (VEKAM, 2014) (Fig. 8**).**

Looking at the facades of the building, it can be said that a minimal but impressive composition has been created with a well-designed balance of fullness and emptiness and material differences formed on horizontal and vertical axes. Large windows have been used on all facades, which has resulted in well-lit interior spaces and eliminated the massive effect of the building. Whether in terms of reflecting the characteristics of the period in which it was designed, providing insights into the housing policies of the years it was built, its unique design approach, or the architectural details it possesses, the İş Bank Houses es are an architectural heritage that deserves to be preserved and protected, despite their 'nakedness' and 'vulnerability' (Şumnu, 2012).

Fig. 8. Floor plans of the İkramiye (Lottery) Apartment Building (Taken from the VEKAM Archive, edited by the Çağla Canca.)

5. Conclusions

Cities construct their own collective memory. Collective memory, formed through the interaction between urban space and time, strengthens the sense of belonging between the city and its inhabitants. Shared memory is a crucial element for the social and physical sustainability of cities. Urban memory is shaped by the sociological and morphological changes experienced by the city, and this influence in turn affects the city's users and, consequently, the city itself. Atatürk Boulevard serves as a memory in its own right for the city.

With Ankara becoming the capital city, the aim of establishing a capital city in accordance with Western standards was pursued, and Atatürk Boulevard, which emerged during this period, has witnessed every transformation the city has undergone from that time to the present day and has undergone spatial changes alongside these periods. The changes that the boulevard has undergone have affected the structures, functions, spatial uses, and consequently the daily lives, habits, and social relationships of the users of the boulevard. In this context, all these changing conditions and interactions on the boulevard affect the collective memory of the city and its inhabitants.

This collective memory is read primarily through public structures and public spaces in Ankara. At this point, the impact of civil architecture, which constitutes a large part of the city's daily life, is directly in contact with daily life, and is shaped within the framework of social components, on collective memory is pushed into the background, preventing the memory from being fully understood.

As observed in architectural imaginations, political and ideological changes across cities and countries, as well as sociological and spatial transformations, directly affect the memory of civil architecture. A new ideology and a new capital city have given rise to a new way of life. Traditional housing couldn't longer accommodate the modernist new society. For this reason, similar to the goal to create a new city independent of the old city, the new capital has produced a new housing typology for itself. In this context, state-supported housing production was initiated first, but due to the inability to meet the capital's growing housing needs and the spread of liberalization policies, housing production began to take place with the support of private institutions.

Within the scope of the above study, these traces were analyzed through the apartment buildings located along Atatürk Boulevard and the side streets feeding into it. In this context, the İlbank Blocks, Cinnah 19, II. Vakıf Apartment and İş Bank- İkramiye Apartments, which addressed the housing needs of the period with various configurations and are significant in terms of memory spaces, were analyzed (Fig. 4).

In the analyzed examples, it is observed that the new modern lifestyle brought about new spatial configurations. For this reason, unlike traditional housing, common use areas such as terraces, pools, and cinema halls that support collective living were integrated into the structures. At the plan scale, elements such as American kitchens and service rooms, which are the characteristic of modernist living, are evident (Fig. 9).

Within the scope of this study, all these changes were analyzed in detail, and the civil architectural memory of the boulevard was examined in a multi-layered manner. It is envisaged that the memory readings of the boulevard will be completed with the missing part of the civil architectural memory. Thus, it has been concluded that when the collective memory of the city is supported in a multifaceted way, these interpretations can be based on a solid foundation.

Building Name	Cultural Functions (e.g., Theatre, Pool, Service areas)	Open Kitchen / Dining room	Modernist architectural elements (Service Window- Garbage Chute- fireplace, etc.	Terrace /Pilotis	Atrium (Gallery Space)	Library/ Work-space	Maid's Room	Modernist Production / Ideological Influence
İlbank Blocks	✓	✗	✓	✓	✓	✗	✗	✓
Cinnah 19	✓	✓	✓	✓	✓	✓	✓	✓
Vakıf Apartment	✓	✗	✗	✗	✗	✓	✗	✓
İkramiye Apartments	✓	✗	✓	✗	✓	✗	✗	✓

Fig. 9. Comparison of Modern Spatial Elements in Selected Residential Buildings (Prepared by Çağla Canca.)

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Tectonics of actively bent gridshell, a holistic design and build approach for weaved timber morphology

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Abstract. Gridshells are one of the most efficient structures that complies minimal use of material, aesthetic morphological composition and functionality of large spans. However, the complexity of its design and build process as well as the relay on multidisciplinary team in design makes it rarely used by engineers. Hence, this research aims to present a design and build approach for weaved timber gridshells, that can help in building a good understanding about the tectonical aspects of such structures; such as (design fundamentals, material behavior, construction technique and details). Due to the nature of such systems that relies mainly on extensive experimental work, the research methodology implies digital and physical experimental simulation for the construction of 1:1 scale model for the proposed approach. Firstly, a digital simulation model were created based on theoretical data to identify the fabrication of elements (members, connections and boundaries). Secondly, a 1:20 physical model created to understand the construction challenges and material behavior of the actively bent members. Finally, a 1:1 scale model was constructed for the proposed approach validation and highlighting the key challenges in large scale construction. As analysis of results the final constructed model showed an achievement of the intended design by 80 to 90% with 10 to 20% deflection due to the difference in scale and procedure of erection.

Keywords: Gridshell; Tectonics; Weaved surfaces; Digital Fabrication; Form Finding.

1. Introduction

Shell structures are a vital architectural element that merges structural efficiency with visual attractiveness, enabling architects to cover large spans using minimal materials. The advent of sophisticated computational design tools, principles inspired by nature, and cutting-edge fabrication methods has sparked renewed interest in wooden shell structures, especially those made from thin, pliable strips that can be bent and interwoven to form intricate shapes. The historical evolution of shell structures indicates a shift from design based on intuition and experience to approaches grounded in scientific and mathematical principles. Early shell designs predominantly utilized compression as their main structural mechanism, with forms inspired by hanging models and physical form-finding methods like the models used by Antoni Gaudi to examine his structural stability that was based on the catenary principles which allowed him to indicate the compression forces within his work (Huerta, 2006) (Fig.1).

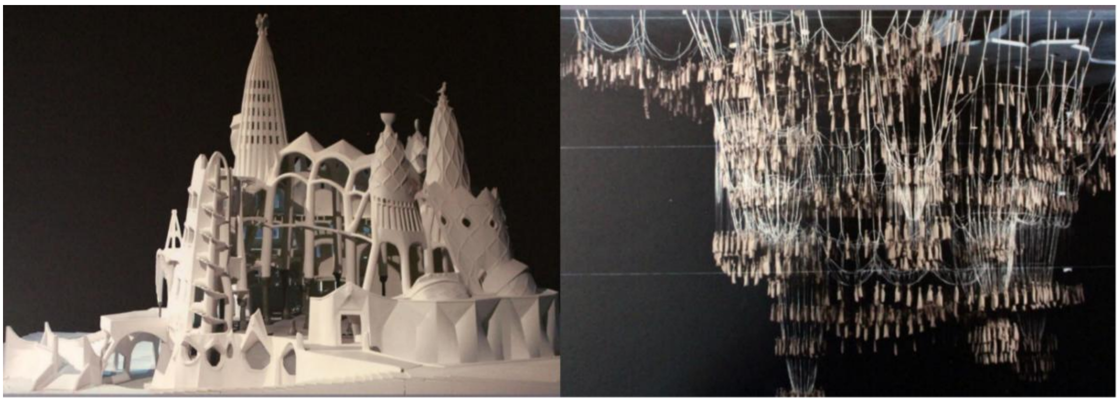

Fig. 1. Model for The Church of Colònia Güell (Huerta, 2006).

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Moreover, the idea and principles of shell structures gained momentum development in the mid-20th century on the hands of Heinz Isler, Félix Candela, and Frei Otto, each of whom introduced unique form-finding techniques that does not only indicate the compression forces but also had the ability to express tensile and bending forces. Hence, these innovators laid down essential principles that still shape modern shell design (Chilton, 2010). While historical shell structures primarily employed materials like reinforced concrete, timber has increasingly emerged as a sustainable option, which helped in the appearance of another shell typology called Gridshells. This typology represent a distinct advancement in shell structures, characterized by the replacement of a continuous surface with a framework of flexible linear segments (Fig 2). These innovative structural systems redefine the traditional notion of shell architecture by utilizing a lattice or grid of slender, adaptable members instead of a solid, uninterrupted surface. In contrast to conventional shells, which are typically made from materials such as concrete or masonry that create a unified surface, grid shells consist of a network of interconnected elements—often crafted from timber or steel—arranged in a regular or occasionally irregular mesh configuration, including shapes like squares, rectangles, or triangles (Pathade et al., 2022).

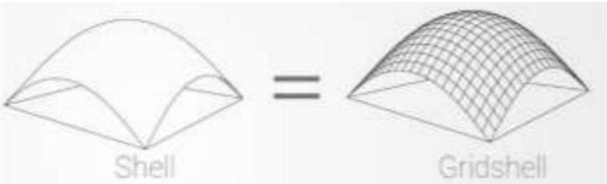


Fig. 2. Difference between Shell and Gridshell (Pathade et al., 2022).

Actively bent wood (elastically deformed) gridshells signify a transformative advancement in architectural engineering, combining structural efficiency with an organic aesthetic. These systems, characterized by their double curvature, utilize the natural flexibility of wood through the elastic deformation of initially flat strips, resulting in self-supporting frameworks that reduce material consumption while enhancing spatial functionality. However, their widespread implementation is hindered by the intricate relationships among material properties, geometric accuracy, and construction processes. Conventional methodologies often compartmentalize the design workflow into separate tasks, such as structural analysis, form-finding, and fabrication planning, leading to coordination difficulties that increase costs and technical uncertainties (Pone, et al., 2015). Hence, the research seeks to overcome these challenges by employing an integrated approach that combines computational design, material experimentation, and full-scale prototyping. Conceptualizing the gridshell as a cohesive tectonic system—where structural principles, material characteristics, and assembly methods evolve together—the study establishes reproducible processes for practitioners.

2. Actively Bent Grid Shell

According to (Huijben, 2011) In 1970 Frei Otto established a new identity for gridshell structure. That kind of shells have the same functional properties of normal shells, its difference is basically about removing an excessive amount of material to create a slender lattice grid pattern, the remaining are the load paths all over the surface. Hence, through the grid shell structure the forces are transferred by discrete or continuous members, not like to the normal shells where the forces are transferred through the whole body. Frei Otto gets his inspiration from the hanging models that was created by Antoni Gaudi, instead of transforming it to a solid sculptures he transform it to a grid shells by inverting the flexible strings hanging models (Fig. 3).

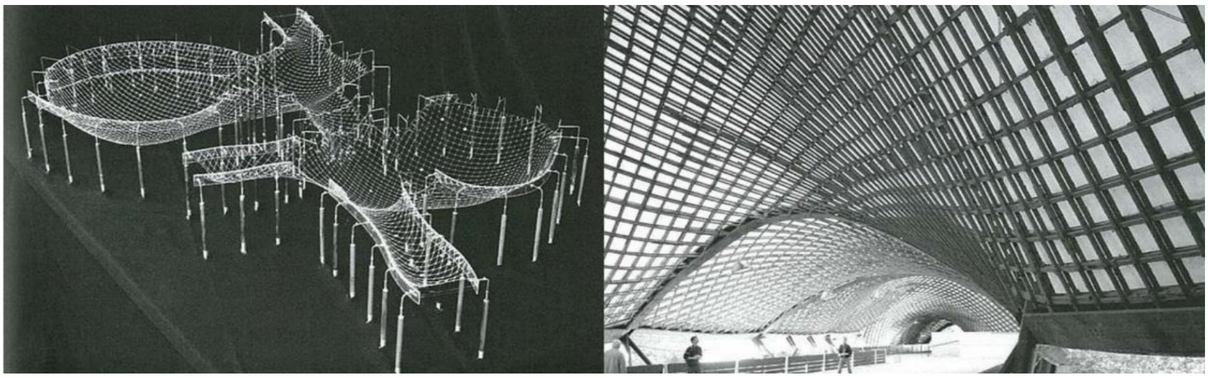


Fig. 3. the grid shell of Mannheim and the hanging model (Huijben, 2011).

From a constructive perspective; grid shells have also different way than normal ones, instead of creating a formwork and cast in-situ reinforced concrete, grid shell construction starts from a planer mesh, the discrete members are assembled on the floor level and then they lifted up or being deformed and pushed from the sides inwards to raise up the shell to get its final shape, after getting the desired shape the connections fixation takes place for the boundaries. Hence, it require the connections between the grid elements to be flexible; allowingScissoring and sliding motion in order to allow the initial deformation of the discrete members, then its fixation after the final shape could takes place if required (Pone, et al., 2015). Actively bent gridshells signify a transformative advancement in lightweight structural design, utilizing elastic deformation to convert flat grids of linear components into stable, doubly curved structures. In contrast to traditional shells that depend on rigid formwork or pre-shaped curvature, these systems generate their geometry through the deliberate bending of initially flat elements (see fig. 4) an approach that takes advantage of material elasticity while reducing fabrication complexity.

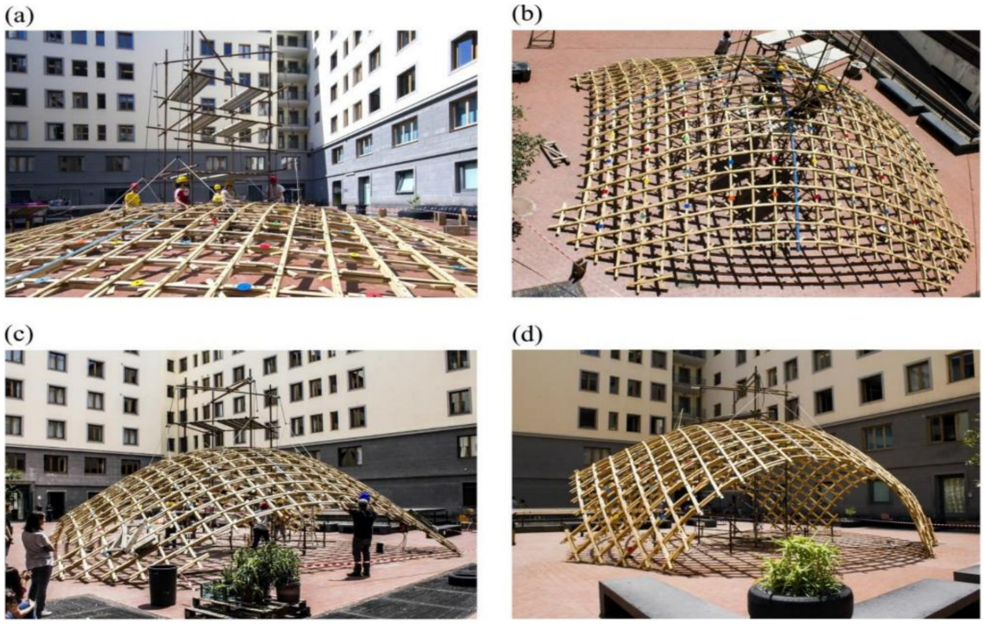


Fig. 3. Toledo grid shell 2.0. Construction process: (a - c) The central nodes are pulled up by means of cables; (d) Additional horizontal trust is added to the corner nodes to reach the final shape (Pone, et al., 2015).

The structural effectiveness of this method is rooted in its capacity to induce advantageous residual stresses during the forming process, as bending moments establish a self-equilibrating stress state that improves buckling resistance under operational loads (Hoyer, et al., 2024). Central to this phenomenon is the interaction between geometric stiffness (derived from curvature) and material stiffness (resulting from member cross-sections) (Pone, et al., 2015). As illustrated by the Weald and Downland Gridshell, the lattice's topology—commonly a quadrangular or triangular mesh dictates load redistribution strategies. Triangular meshes demonstrate enhanced torsional rigidity, thereby decreasing the need for bracing, while rectangular grids necessitate rigid joints to alleviate shear deformation. According to (Herda, et al., 2024) the Savill Garden Gridshell serves as a prime example of this concept, achieving a 60-meter span with 50 mm-thick laths through optimized mesh aspect ratios. In Conclusion, elastically deformed gridshells have key attributes that control their morphology, which are:

- Material Orthotropic: Wood is an anisotropic heterogeneous material. Hence, there is a bending stiffness difference when it bend along /versus the grain. Also, the slenderness ratio must balance the flexibility and buckling resistance (Beak, et al., 2018).
- Mesh Topology: Weather triangular, rectangular or geodesic hybrid, each one have a pros and cons. For examples; triangular are superior in torsion resistance and shape conformation. Rectangular are much easier in construction. Geodesic is in between (Goodarzi, et al., 2023).
- Boundary Condition: Mainly control the shape of the grid shall and play an important role in its stability (Beak, et al., 2018).
- Execution Sequence: Mainly based on controlled deformation from planner elements to curved element. Hence, it can minimize and maximize the residual stresses. For example sequential relaxation minimize overstressing on the bending members. But it is critical in maintaining the shape and could cause geometrical deviation (Beak, et al., 2018).

- Joints and Connections: The orthogonal joints between members must allow a scissor motion while erection. the connections could be made out of normal pins to hold the grid members together and also allow the scissor motion (Adriaenssens, et al., 2014). For thin plywood layers, it is typically more advantageous to utilize several continuous connections rather than a few larger ones, which impacts the advancement of innovative jointing methods.

3. Weaving Behaviour

Interwoven actively deformed grid shells constitute a distinct category of elastic grid shells, characterized by the interlacing of orthogonal timber laths into a textile-like framework, which is subsequently elastically shaped into doubly curved geometries. This construction technique capitalizes on the natural flexibility of wood while harnessing the structural advantages offered by woven configurations. The Tsinghua University grid shell sphere project exemplifies this approach, where the orthogonal interweaving of glass-fiber-reinforced polymer (GFRP) rods facilitated geometric self-stabilization through frictional interlock, resulting in a sphere with a diameter of 4 meters, supported solely by 3D-printed nylon hinge joints (Huang, et al., 2022). When applied to timber, this methodology presents distinct material challenges: the orthotropic nature of wood necessitates precise alignment of the grain direction with the primary bending axes to avert radial cracking during the forming process (Tang, 2012). Frictional interlock serves as an essential stabilizing mechanism in grid shells, especially those made of woven or elastically bent timber laths. This phenomenon occurs due to the interactions among structural components at their contact points, where friction opposes relative movement and redistributes loads (Huang, et al., 2021).

3.1. Behavior of wood Woven Morphologies

The orthogonal interlacing of timber laths creates a textile-like matrix that behaves as a continuous shell while maintaining discrete member identities. This duality offers distinct advantages:

- Geometric Self-Stabilization: The frictional interlock among intersecting laths effectively counters shear deformation, as evidenced by the GFRP sphere project at Tsinghua University. The prototype, measuring 4 meters in diameter, attained stability through: Orthogonal Weave density, interlacing Friction, and Number of layers. When it applied to wood a calibration must be made to counter the orthotropic nature of the wood. (Carrol, 2024).
- Torsional Stiffness: weaved systems show higher torsional resistance due to the Frictional intersection of two orthographic directions (Huang, et al., 2022).
- Shear Resistance: Dry Friction at cross members intersection increase the shear resistance.
- Buckling Resistance: the geometrical interlock converts the bending moment into membrane forces (Carrol, 2024) .
- Damage Resistance: in weaved systems when failure happens in one members 65% of the load at this point will be transferred to the adjacent members. On the other side, in single layer gridshell only 40% will be transferred (Huang, et al., 2022).
- Stress Concentrations: at the points of crossover the local bending moments increase by 2.5x (Caffarello, et al., 2022).
- Adjustments: due to geometrical lock, any post erection adjustments are hard to be done due to the friction between the members (Soriano, 2017).

4. Form-Finding

The methodologies for form-finding in shell structures have undergone considerable advancement, with modern techniques utilizing both physical modelling and sophisticated computational methods. These approaches seek to identify forms that are not only structurally efficient but also architecturally expressive.

According to (Fig.5) form-finding of shell structures composed of two main categories which are the digital form finding and physical form finding. Both methodologies are important and each one serve a unique feature in shell systems validation. The techniques of physical form-finding have a rich history in the design of shell design, tracing back to the hanging chain models of Antoni Gaudí and the frozen fabric forms developed by Heinz Isler.

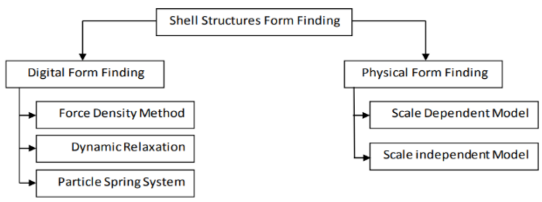


Fig. 4. Form Finding Types (Author, 2025).

These methodologies utilize physical forces to create shapes that are structurally optimal. It is important method, enabling designers to investigate structural behaviors via hands-on experimentation (Pone, et al., 2013). According to (Addis, 2014) "Designers of structures have used small-scale models when it is beneficial to do so, especially in order to raise the engineer's confidence in the design being proposed. This may have been for one of many reasons. For example:

- The existing calculation methods were too complex or time-consuming.
- The high cost of full scale prototype.
- It was believed that conventional analysis methods are not sufficient to model the structure.
- The structural geometry could not be defined by mathematical equation.
- The type of structure was unprecedented.
- There were no other means available. "

Moreover, Contemporary approaches to form-finding in shell structures are progressively dependent on computational tools that replicate physical forces and material properties. The advent of digital form-finding techniques has transformed the design process, allowing for the investigation of intricate geometries and structural enhancements that would be challenging to realize through traditional physical modeling methods (Pone, et al., 2013). Digital form finding have a lot of methods, one of them is the dynamic relaxation method which is the most suitable one for the active bending grid shells because of The ability of the method to integrate the material structure strain within the form finding process, make it able to be used in the form finding of grid shells that made of materials with high bending rigidity (material resistance towards bending) like wood, steel, and composite materials (Adriaenssens, et al., 1999) because the erection of grid shell happens by bending a planar grid as mentioned before. For example if the grid shell is made out of dense wood and a bending is applied (stress) at a certain value the wood will broke as strain behavior. The DR method process is to observe on a high frequency the behavior of each node (intersection of members) on the grid shell against artificial kinetic damping, until the nodes becomes at rest (Fig. 6). The artificial damping is then increased until it becomes equivalent to the material potential energy and stops. Which can conclude that the material got its apogee of kinetic force record to define its maximum state of bending stress, where afterwards the stress will result in a material failure strain (Barnes, 1999).

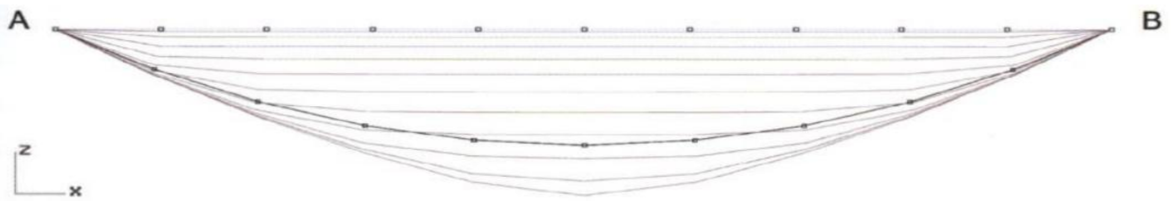


Fig. 6. example on kinetic damping behaviour from initial state to final geometry (Barnes, 1999).

4.1 Particle Spring System (PSS).

Dynamic Relaxation had been used for decades in order to aid with the physical form finding, but they are not easy for architects to use, as it based on difficult mathematical understandings (Kilian & Ochsendorf, 2005). On the other side Particle Spring Systems have a less complex version of dynamic relaxation method that can be used by architects in order to simulate the behavior of deformable bodies. In addition, it allows architects to simulate and update forces, physical properties and supports in real time (Tedeschi, 2014). The use of PSS method became popular after the development of CADenary software by John Ochsendorf and Axel Kilian, this software enables the user to manipulate the variables of the process virtually. According to (Kilian & Ochsendorf, 2005) , the method involves the use of particles in form of points resulting from a grid intersection lines and springs in form of lines of the grid connecting the points, then all the mass is concentrated in the particles, and the springs act as a straight linear elastic bars and each one is assigned a constant axial stiffness with an initial length and final length with a damping factor, which can be changed in real time simulation (Fig. 7), hence. From a scientific prospective Particle Spring Simulation could be described as follow:

"Particle-spring (PS) simulation finds steady-state equilibrium by defining a mesh topology for a network of lumped masses, called particles (nodes), and linear elastic springs (bars), and then by equalizing the sum of all forces in the system through motion. Out-of balance forces arise due to the stiffness and geometric lengths of the springs and gravity loads acting on the particles. The solution is often obtained by higher order explicit, or by implicit integration." (Bhooshan, Veenendaal, & Block, 2014) P.113.

PSS when used to simulate structural models, it is preferred to use implicit solvers, because it assumes springs (elastic bars) with high stiffness which minimize the deformation of the spring's length (Baraff, 2001). Also for validation and reliability, in the project of the Almond Pavilion that was simulated using particle spring system. The results attained a geometric fidelity of 92% between the simulated and constructed forms, while also decreasing the analysis duration by 40% in comparison to Finite Element Analysis. The system's user-friendly nature arises from the direct manipulation of visual parameters, such as spring stiffness and friction coefficients, instead of relying on abstract engineering metrics (Soriano, 2017).

According to (Tedeschi, 2014) in his book AAD_ Algorithms Aided Design, clarified the process in simpler way, by defining each element in the process as follow (Fig.7):

- Particles (Members Intersections): each node in the system is a lumped mass, that changes coordinates and velocity as the simulation runs.
- Springs (Grid members): a spring is an elastic linear connection between two nodes that behaves according to the Hooke's law: a spring has an initial resting length and a stiffness value (k).
- Forces (Axial): weights and external loads are simulated by vectors that are applied exclusively to the nodes.
- Anchor Points (supports): particles that do not change position during the simulation.

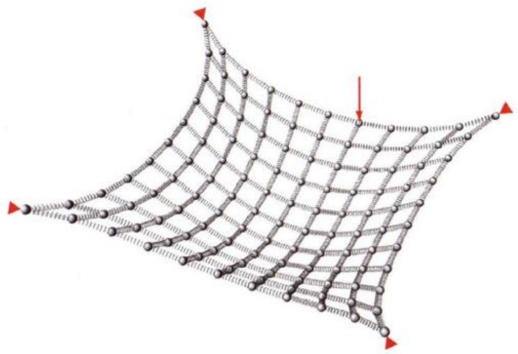


Fig. 5. Illustration for the PSS simulation elements (Tedeschi, 2014).

5. Weaved Gridshell Prototype (Sayesh Pavilion Method).

The aim of the research is to provide a simple method that can be used by architects in order to design and build weaved gridshells that made of wooden strips. Also, the approach must consider the key attributes of weaved gridshells that were previously mentioned in the theoretical study and their application in a prototype model.

The prototype model was designed to cover two pathways the one on the right is 4.6 meters span width X 7 meters length and 3.1 meters height. The one on the left is 1.7 meter space width X 3 meters length and 2.3 meters height. The used wood is yellow southern pine 15% moisture content with thickness of 6 mm for the width members and 4 mm for the length members.

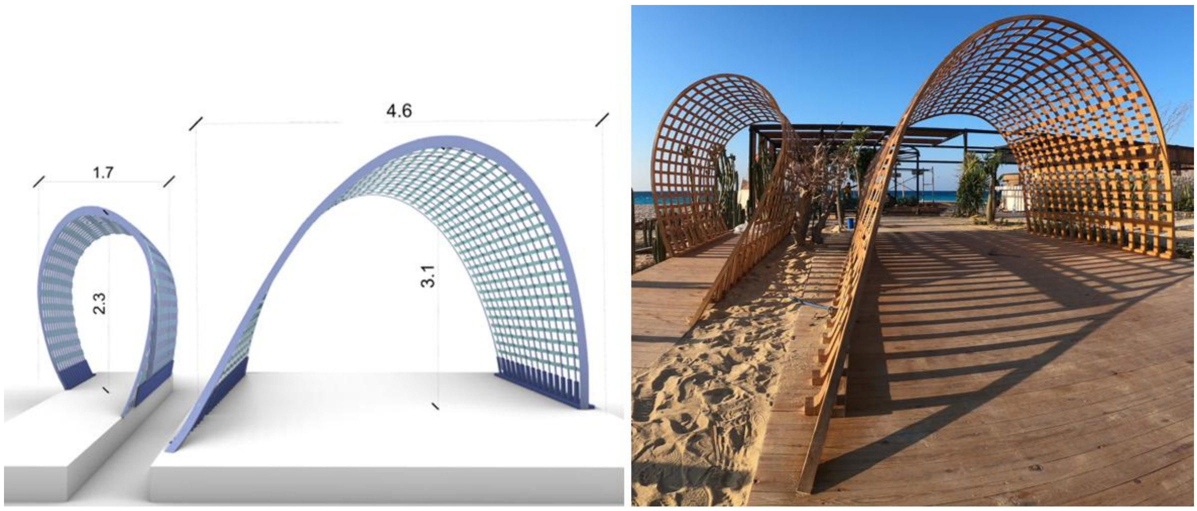


Fig. 6. on the left side the initial design for the prototype and on the right side the executed one (Author, 2025).

The prototype as presented in the above figure. In order to be executed a sequential process with feedback loops must take place (Fig.9)

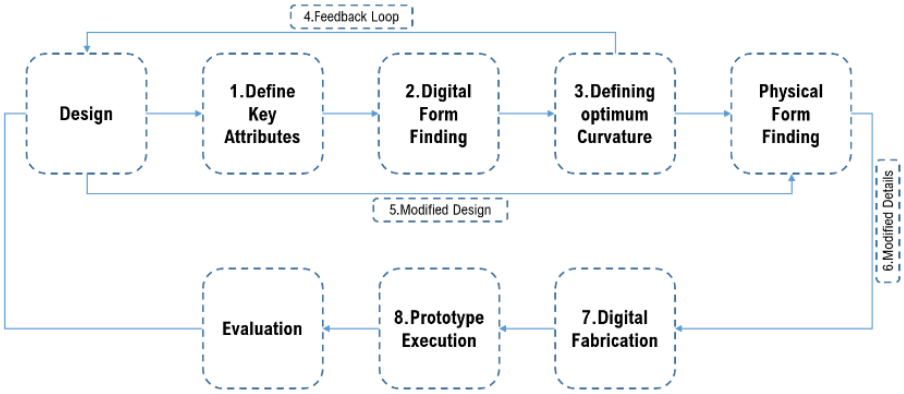


Fig. 7. the sequential process of developing weaved gridshell prototype (Sayesh Pavilion) (Author, 2025).

5.1. Defining Key Attributes.

According to the theoretical study, weaved grid shell key attributes start with the boundary condition which give the shell its shape and curvature profile, in the research prototype it was designed as straight lines with multiple fixed anchor points that was fabricated as part of the system curvature, which will constraint the starting point angle and ending point angle of each member in the x axis. Second attribute is the connections, for the boundary it was designed to be fixed using lose screws during erection and got tightened after achieving the desired curvature, for the interlace connection it was designed to be depended on the frictional interlock. The third attribute is the material orthotropic consideration, as all the bending must be done along the grain, which is considered while cutting the wood. The fourth attribute is the mesh topology, since the weaved grid shells have high torsional stiffness and frictional interlock, the topology chosen is quadrilateral for the ease of construction. Finally, the erection sequence in this prototype, the erection was sequential for the grid members, as that will early guide the process about failures, because the aim of the design is to be constructed without structural calculation. Hence, manual testing approaches was considered for failure indications (Fig.10).

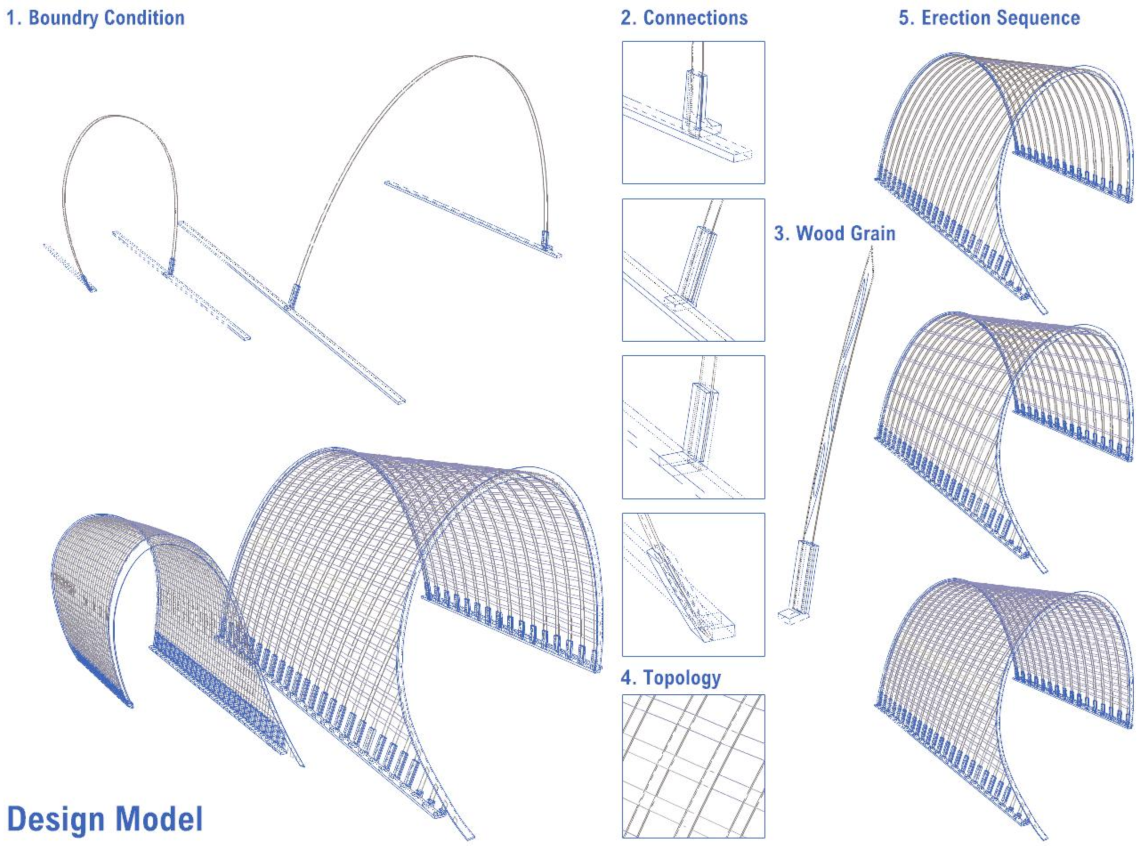


Fig. 8. the designed model with the key attributes details (Author, 2025).

5.2. Digital Form Finding.

At this stage the form finding was done using particle spring system method in Kangaroo plugin / grasshopper. The idea of the simulation is to figure out the right curvature for the wood bending behaviour. The simulation process started by defining the geometry to simulate. In the research case, the geometry chosen was the first and last member of the grid shell, since they have the maximum and minimum bending stress, and all the in between members are a range between the maximum and the minimum. After that the grid member is identified as a set of connected triangular mesh faces and the connecting line defined as axis of rotation for bending with a constraint for the angle to be Zero degree. Finally, starting and ending points of the grid member is identified as anchor points then sideward and upward force is applied. The previous composition of simulation inputs are sufficient to make a geometry act under bending behaviour (Fig.11).

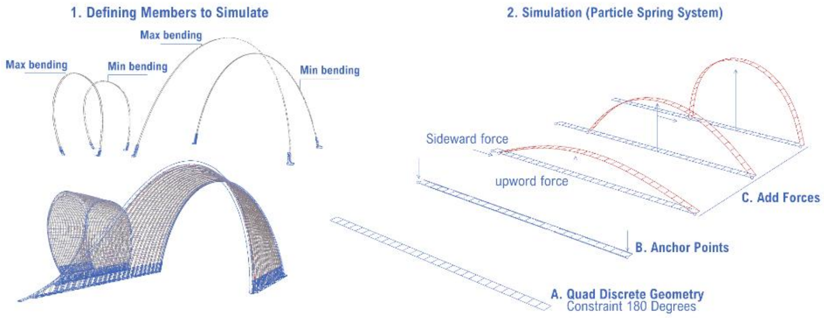
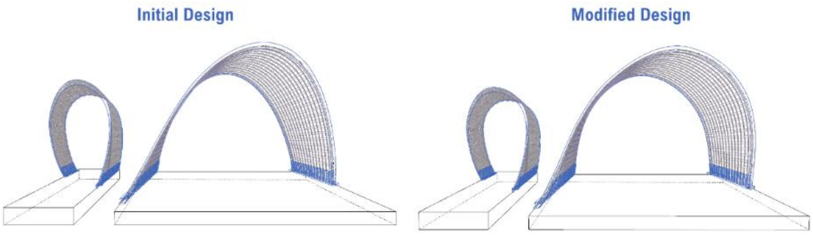


Fig. 9. digital form finding process illustration using kangroo plugin (Author, 2025).

5.3. Defining Optimum Curvature.

The last step about the digital fabrication process. Showed there a difference between the designed curvature and the curvature resulted from the simulation. Hence, a feedback loop into the initial design at this stage is necessary in order to get the most accurate data to be fabricated for physical form finding (Fig.12).

Fig. 10. the difference between the initial design and the modified design (Author, 2025).



5.4. Physical Form Finding.

At this stage a full model with all the details is made on a scale 1:20. The model intention was to test the connections, boundary, bending behavior, and erection method. As concluded from the model, firstly the joints of the x axis members in order to get the exact length with a good bending behavior need to be overlapped by 50 cm in real prototype and this to avoid bending bumps. Secondly to get more bending stiffness for the entire system, 1/4 of the y axis members need to be wider. Finally some member of the y-axis got cracked while erection due to the slenderness ratio (Fig.13).

Fig. 11. the physical form finding model (Author, 2025).

5.5. Prototype Execution.
After the analysis of physical model and consideration of results. Digital fabrication drawings and files were issued for the prototype execution. The execution was done based on sequential process as planned (Fig.14).

Fig. 14. the process of sayesh pavilion execution (Author, 2025).

6. Analysis of results

The final prototype show an 80 to 90% of achievement related to the modified design after simulation. That based on the accuracy of dimensions and the bending curvature profile the prototype take (Fig.15).

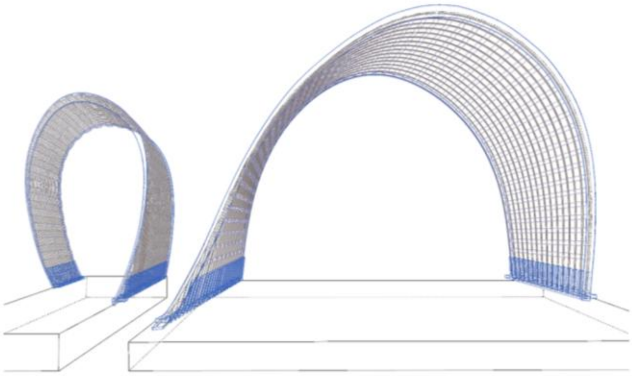


Fig. 15: comparison between the designed model and executed prototype (Author, 2025).

Although, a few problems appeared in the prototype that needs further development and research (Fig16). Firstly a safe ranged side buckling observed. Hence, the slenderness ratio of the x axis members need to be lower for more bending stiffness which will result in creating of a smoother curvature profile. Secondly, the weaving shows bumps in some of the areas which resulted due to the presence of minimal double curvature within the entire shell. Moreover, the joints for creating continues members need to be less stiff, its stiffness were because of the joints overlapping. Finally as a disadvantage of the sequential erection technique, the weaving activity of the last few y axis members were hard to install due to the increase of interlocking friction.

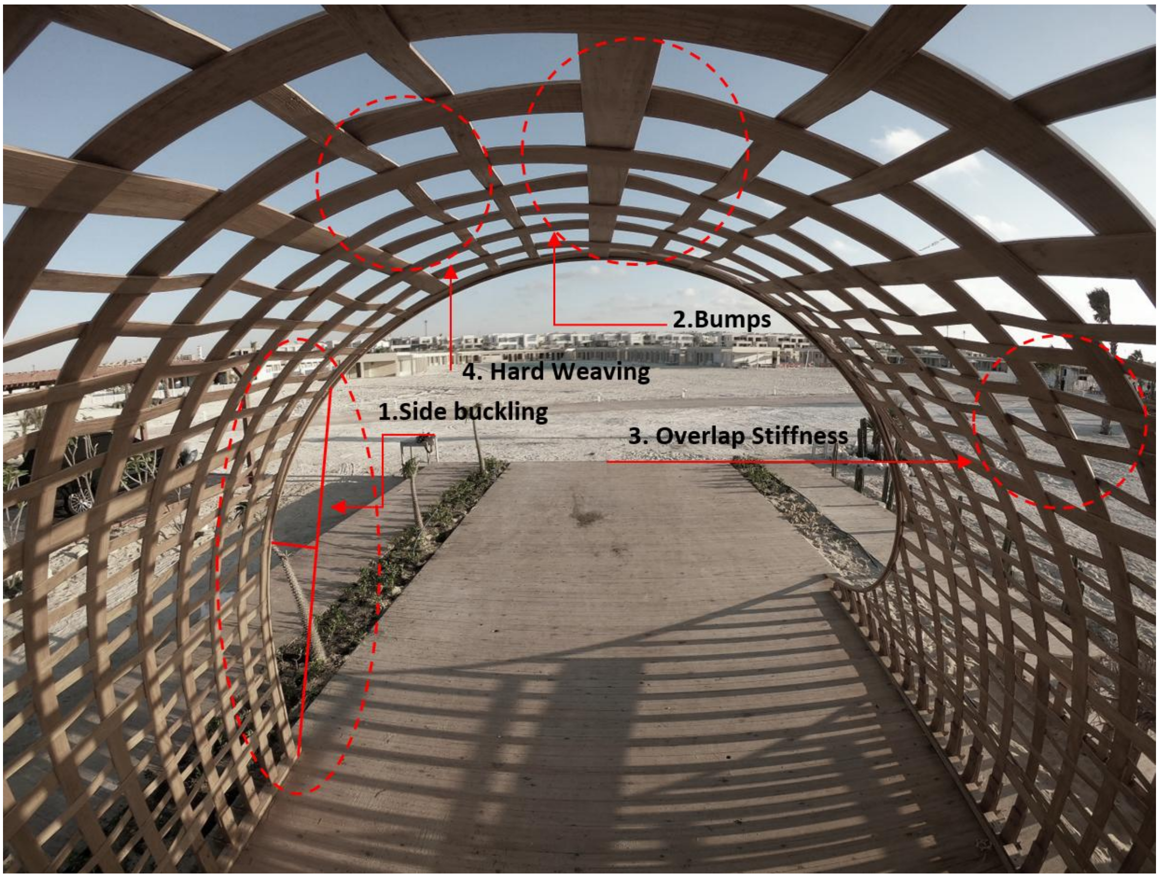


Fig. 16: photos highlighting the key problems in the prototype (Author, 2025).

7. Conclusion

The field of active bending gridshells, still need more research to fill the gaps related to the ease of simulation and fabrication by architects, as it is a multidisciplinary subject due to the combination of morphological aesthetics and structural performance. In addition, the material physics and behavior under different stresses need to be studied by architects, because it give an insights about the material ability and limitations. Moreover, the physical modeling and prototyping still modest to use as it helps in the phenomenal study and observation, like the hanging models, tensile membranes and soap film models. On the other side digital form finding is also very important as it fill the missing gaps related to the simulation and form finding scale.

The theoretical study showed that the idea of shells form finding have several ways and the software development and CAD programs avilable now make it much easier and faster.

The outcomes of each step in the making of the prototype, open the gate for research activity. As the relation between the physical form finding and digital form finding need to be linked to increase the performance of the process. Also the slenderness ratio in relation to the span and holistic shell morphology still an open subject and that because of the wood is a natural material that can behave differently depending on its molecular structure. In summery:

- the final executed prototype validet the Sayesh Pavilion Mehtod by almost 80 % .
- the key challenges for this method is the weaveing technique and slanderness ratio of the used wood.
- The combination of particle spring system method and physical modeling shows a good relaiability but it needs numerous experimentation to get the optimum values.
- The sayesh method represent a tectonic cohesive system for active bending weaved gridshell, as each detail and activity exist for the pavilion erection is a key stone in the end result
- This method is suitable mostly for single curved bending surfaces, more research need to be done for its application on doubke curved surface and freeforms.
- The interlock stiffness of weaved surface have its pros and cons. As it helps in interloction parts together with increase in the torsional resistance, but it also can results in bumped surfaces if it is not well considered.

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Examining the earthquake behavior of Kırıkkale historical steel bridge with numerical analysis

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Abstract. This study was conducted to investigate the seismic behavior of the historical steel bridge located in the province of Kırıkkale and the measures to be taken to improve such behavior. Historical structures are exposed to various effects from the time they are built to the present. To predict the potential permanent damage that natural disasters such as earthquakes may cause to structural systems, it is necessary to establish the numerical models and calculations of the structures. These studies involve an interdisciplinary process that includes architectural and restoration expertise as well as civil and earthquake engineering. Within the scope of this study, the time history analysis method, which allows the nonlinear evaluation of the dynamic structural response of structures under loading that varies with time, was examined among structural analysis programs and methods used in analyzing historical bridges. In this context, the Kırıkkale Iron Bridge, which was built in 1906 and is known as the first iron bridge in Turkish architectural history, was selected as a case study to shed light on the seismic behavior of historical bridges in our country.

Keywords: Historical structures; Earthquake; Numerical analysis; Time history analysis

1. Introduction

Investigating the seismic behavior of historical structures is of great importance in terms of restoration studies. The accuracy of these studies depends on the correct analysis of the load-bearing systems of historical structures. Structural analysis of historical buildings differs from the design of load-bearing systems of new constructions, as it aims to calculate the stresses and internal forces resulting from self-weight, wind, earthquake, ground settlements, and various other loads or physical external effects during use. The stresses and internal forces obtained from these calculations are compared with the load-bearing capacities or limit stress values determined for structural elements (Lourenço, 2002; Pena et al., 2010). This type of calculation and comparison is called the linear elastic approach. However, historical structures are complex in terms of both load-bearing systems and material properties. Therefore, understanding and utilizing nonlinear structural analysis methods is highly important not only from an engineering perspective but also in the fields of architecture and restoration.

In this regard, the steps required to determine the earthquake performance of historical structures using nonlinear time history analysis are addressed in this study. The method is explained in detail through the example of the Kırıkkale Historical Iron Bridge, which represents one of the earliest examples of this method.

Among transportation structures, bridges built to overcome natural obstacles are undoubtedly the most significant elements. Throughout history, numerous bridges with varying material properties and functional characteristics have been constructed. Among them, iron bridges, which have evolved alongside material development, are particularly significant due to their functionality, load-bearing capacities, and the spans they cover.

Following the widespread production of pig iron through blast furnace methods in 18th-century England, the use of iron as a construction material became possible. The first engineering structures built using iron were bridges. Many iron bridges built in the 19th and early 20th centuries are still in use today. These bridges, which have remained functional for over a century, have been subjected to loads that gradually change the structural and material properties of the bridge.

Examining the structural health of iron bridges still in use within the railway network or registered as cultural heritage is of great importance for prolonging their service life. In recent years, many historical bridges have undergone structural health monitoring, and the structural variables obtained from these observations have been incorporated into numerical models for more realistic earthquake analyses.

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In Turkey, structural analysis studies have been conducted on many stone arch and iron bridges during restoration projects by the Historical Bridges Department of the General Directorate of Highways.

Examples of structural analysis and repair works on iron bridges are examined within the scope of this study. In the structural analysis of the historical Silahtarağa Bridge in Istanbul, it was found that the bridge could safely carry a pedestrian load of 400 kg/m² and, under exceptional circumstances, a vehicle load of up to two tons; however, it did not meet seismic resistance requirements in its current state. A stability analysis was performed for the historical Yatağan Dipsiz Stream Bridge, which was damaged in 2005 and partially suspended over a temporary support in the streambed after losing some of its load-bearing elements. In this analysis, the compatibility of the undamaged existing elements with the new ones planned for reconstruction was examined. Based on the analysis results, the restoration project proposed preserving the original sections and reconstructing the destroyed parts with materials compatible with the original. Structural analyses were also conducted for the 65-meter-long historical Çamçavuş Iron Bridge in Kars, which was planned to be relocated in one piece due to submersion by a dam reservoir. These analyses showed that during lifting with a 100-ton crane, the diagonals near the newly created support platform were stressed but remained within safe limits. It was also found that the bridge remained stable under its own weight. However, during transport, if the road gradient exceeded 15% or in cases where diagonally opposite supports were suspended during turning, diagonal connections were severely stressed. Finally, after being relocated, the analysis showed that when vehicles crossed the bridge, the stress/capacity ratios of the structural elements remained below critical limits (Sert and Partal, 2015).

National and international literature also includes many studies on updated bridge models based on structural health monitoring results, with significant findings and recommendations regarding their seismic performance.

Özçelik et al. estimated the modal parameters of a steel railway bridge operated by TCDD through experimental field studies and developed reference numerical models for the bridges (Özçelik et al., 2018). Siriwardane et al. determined the modal parameters of a six-span steel railway bridge during the passage of the heaviest train. A finite element model was evaluated based on displacement and stress data collected from the bridge, resulting in an updated finite element model. In this study, a damaged model was also created by removing potentially damaged structural elements from the updated model, and modal parameter estimations were made to identify changes caused by damage (Indika et al., 2015). Spyrakos et al. conducted an experimental and analytical study to assess the condition of a historical railway steel bridge. The seismic load-carrying capacity of the historical bridge was determined, and the analytical model of the bridge was updated based on static and dynamic field measurements (Spyrakos et al., 2004).

Within the scope of this study, the seismic behavior of the Kırıkkale Iron Bridge—which is one of the oldest iron bridges built in Anatolia and is still standing—will be examined in detail. In this context, restoration project reports of the bridge, which has undergone significant natural and human interventions over time, were reviewed. Load-carrying capacity calculations of the structural profiles concluded that there was no loss in carrying capacity (Highways, 2010). However, in the event of a potential earthquake in this region, analyzing the seismic behavior and potential damage zones of the bridge is of great importance.

2. Material

According to the information provided in the inventory card of the bridge issued by the 4th Regional Directorate of the General Directorate of Highways, the Kırıkkale Iron Bridge is also referred to as the Abdülhamit Bridge. Located over the Kızılırmak River in the Yahşihan District of Kırıkkale Province, the Iron Bridge was commissioned by Sultan Abdülhamit during the late Ottoman Empire. Construction began in 1905 and was completed in 1906 (Fig. 1). The Iron Bridge was registered as a historical monument by the Ankara Regional Council for the Conservation of Cultural Property on 20.11.1995 under decision number 4341. The most recent conservation and restoration projects were approved by the same council on 21.10.2010 under decision number 5482 (Fig. 2).

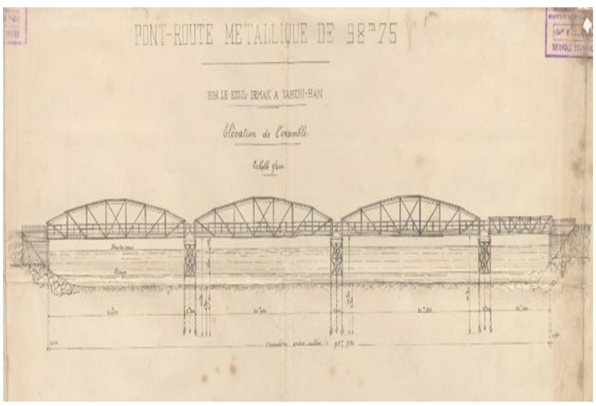

Fig. 1. Architectural drawing of the Iron Bridge and Current view of the Iron Bridge

The three central piers of the bridge are seated on a screw pile system. The total length from the bottom level of the main girders to the tips of the piles is 11.00 m, of which 6.00 m are piles driven into the ground. The piers, including the bearing pads, have a height of 5.00 m. In each pier, the distance between the outermost of the six screw piles is 2.30 m. On both the upstream and downstream sides of the central piers, metal pipes are arranged in a triangular formation, protruding 2.07 m from the main truss in plan view, reminiscent of classical stone cutwaters. The two end supports of the bridge were built using ashlar masonry. On both facades, three main truss spans with flattened arches are expressed across seven bays. Except for the central bay, the other bays are connected with single diagonal profiles, while the central bay is formed by intersecting diagonal members. The three left bays, from upstream to downstream, are constructed with diagonals sloping from left to right, while the three right bays slope in the opposite direction. The trusses with clear spans of 26.95 m are divided into seven equal segments, each 3.85 m in length. Another span, composed of four straight trusses, includes six bays. The two end bays on each side are formed with single diagonal profiles, while the two central bays use intersecting diagonals. This span is divided into six equal parts of 2.00 m each, totaling 12.00 m in length. Thus, excluding the abutments, the total length of the bridge is 98.75 m, and including the piers, it reaches 116 m. The height of the trusses starts at 2.00 m at the ends and increases to a peak of 4.58 m at the central bay. Diagonal bracing elements are placed above the trusses to connect them (Fig. 2).

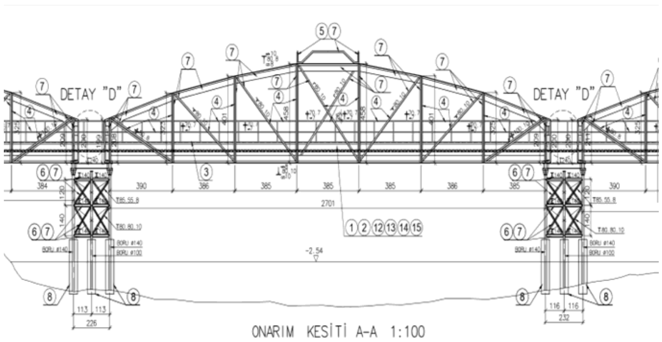

Fig. 2. Survey and restoration project (Highways, 2010)

The distance between bearing axes is 4.00 m, while the platform width is 3.61 m. Each bay contains four longitudinal girders supported by eight transverse girders. Diagonal braces connect the intersections of the longitudinal and transverse girders. The deck is covered with a material known as "zores iron" (omega plate), a fabricated profile with a reverse "S" shape that started being used in the second half of the 19th century, especially for railways. These elements range in length from 80 to 600 m. Pumice stone, a lightweight material, was spread over the zores iron to fill the gaps, followed by the placement of concrete and a wear layer. The original deck material is unknown, but it is currently finished with stamped concrete. Before the 2011–2013 restoration, the deck was asphalted. It is believed that the bridge might have originally been paved with cobblestones. The railings were made with iron elements measuring 50x50x5 mm.

Except for the ashlar masonry abutments filled with rubble and mortar, the monolithic railings on the abutments, the deck pavement, and the substructure of the deck, the entire bridge is made of iron. The truss system was formed by riveting standard structural profiles and using bolts and screws for some railing components and flat bars. Expansion joints, which allow the iron to accommodate thermal expansion and contraction, are placed between the trusses at the pier locations to allow independent movement of the structural system (Nas, 2024).

2.1. Numerical Analysis Methods and Nonlinear Time History Analysis

The purpose of numerical modeling is to determine the actual behavior of the entire structure, a specific part of it, or its load-bearing elements under various loads or environmental effects. The structural system of historical buildings and monuments is often highly complex. Therefore, many simplifications must be made when modeling such structures. In order to obtain a simple and straightforward model, the mechanical properties of the materials comprising the structural elements must also be accurately defined (D'Ayala and Speranza, 2003). The numerical model, also referred to as the Finite Element Model, is created by assembling finite elements to represent the overall behavior of the structure. In finite element analysis, the behavior of individual elements and the entire numerical model are both important (Mallardo et al., 2008). The following individual element types with defined geometric properties are generally used in finite element analyses:

- Beam or Frame Element: This type of linear element exhibits bending and shear deformation in both axes, as well as axial and torsional deformations. A typical beam element has six degrees of freedom. In numerical models used for structural analysis, node coordinates are defined relative to a global coordinate system. Finite elements also have their own local coordinate systems.
- General Shell Element: Shell or plate elements are used in the structural analysis of shells, slabs, walls, and any spatial forms. Shell or plate elements are typically formed by connecting three or four nodes to create triangular or quadrilateral shapes. Depending on the type of analysis, each node in the numerical model has four degrees of freedom. Local axes are used to define internal forces and stresses resulting from calculations. Local axes are usually determined by the sequence in which the nodes are listed.
- Three-Dimensional Solid Element: Also known as "brick" elements due to their shape, these elements typically consist of eight connected nodes. At each node, which has six degrees of freedom, the stress and deformation results are calculated along the global axes. They are used to model massive, three-dimensional structural components and load-bearing elements. Since the structure examined in this study is an iron bridge, the system was modeled using frame elements (Fig. 3).

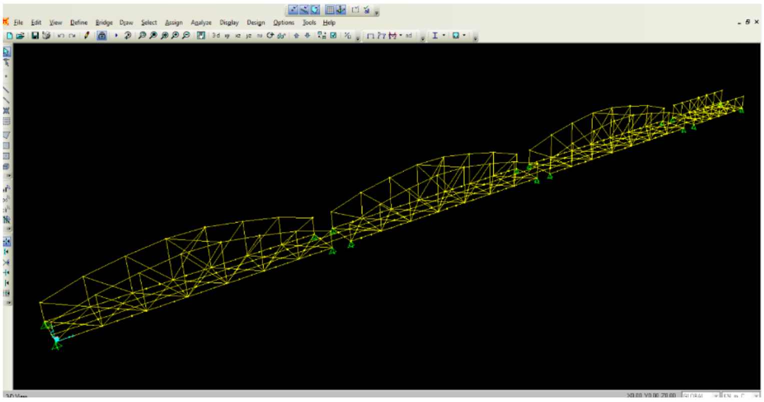

Fig. 3. Modeling the Iron Bridge using SAP2000

Linear analysis in the time domain is not a design method for creating a structure from scratch but rather a sophisticated analysis technique used to verify whether the load-bearing elements of an already designed structure have been effectively dimensioned. Compared to conventional design methods, this approach allows the designer to reach optimal solutions with a lower budget. When the mathematical model of the structural system is solved step by step—by defining the nonlinear behavior of structural elements based on their material and cross-sectional properties and updating the stiffness matrix at each step—the process is referred to as nonlinear time history analysis, or in other words, nonlinear dynamic analysis (Budak, 2015).

In nonlinear time history analysis, the effects of stiffness and strength degradation of materials—especially concrete and steel—before and after cracking or yielding are taken into account. These effects are considered both at the element level and at the overall structural system level (Başot, 2010).

3. Method

In this section, details of the nonlinear time history analysis conducted using the SAP2000 software are provided, including the creation of the analytical model of the Kırıkkale Steel Bridge in the software and detailed analysis settings.

3.1. Time History Analysis with SAP2000

The analysis method that considers the nonlinear behavior of the material and the time-dependent variation of loads acting on the structure is called nonlinear time history analysis. This method is the most effective for realistically estimating the response parameters of structures under earthquake effects. In this method, the equations of motion of 31 structural systems, including time-dependent seismic loads acting on the structure, are solved step-by-step. At each step, the displacements, rotations, and internal forces in each element are calculated. The effectiveness of this method in predicting structural responses depends on the accuracy of the structural model and the appropriate selection of earthquake ground motion records.

During the nonlinear time history analyses, both material and geometric nonlinear behaviors were considered. Plastic hinges were defined at the beginning, middle, and end points of each beam element using the fiber PMM plastic hinge module within SAP2000 (SAP2000, 2000). For geometric nonlinear behavior analysis, the large displacement rule was utilized. The Newmark direct iteration method was used for time history analysis. Analyses were conducted for three directions of earthquake records: two horizontal and one vertical.

3.1.1. Creation of the Numerical Model

The finite element model of the Steel Bridge was developed based on the modeling features and rules of the SAP2000 software. All geometric dimensions and measurements necessary for creating the analytical model of the structure were obtained using previously prepared architectural surveys. Modeling and calculation parameters are listed below:

- Considering the construction period of the bridge, it was assumed that the steel material used belonged to the ST 37 steel class, and the model was created using the properties of ST 37 steel.
- The bridge is suitable for modeling with frame (bar) elements.
- The base model used in calculations consists of 415 nodes and 782 frame elements.
- The material properties of the structural elements were selected based on prior studies on similar structures published in internationally refereed journals and international literature recommendations, as well as values suggested by the current Earthquake Code for steel structures.
- Determining the damage limit states in bridges plays a critical role in assessing the seismic performance of the bridge. Since each bridge element may possess different characteristics, the damage sustained by each component and the overall structure may vary. The damage states of bridge elements were defined using the four damage states described in HAZUS-MH (FEMA, 2003): slight, moderate, extensive, and collapse. Each damage class is determined based on the corresponding loss in serviceability and the time required for repair (see Table 1 and Table 2). In this way, when evaluating the damage in different components, the effects of these damages on the overall bridge are taken into account. As a result of analytical studies, fragility curves were obtained for each bridge element separately, allowing for a performance-based seismic evaluation of each element and determining which components should be prioritized in retrofit measures (Yılmaz and Çağlayan, 2018).

Table 1. Moment-curvature damage limit values for steel elements.

Component	Damage Limit Values			
	Slight	Moderate	Extensive	Collapse
Beam rotation ductility $\mu\varphi$	1	3	6	8

Table 2. Bearing displacement damage Limit States (Nielson, 2005)

Component	Damage Limit Values			
	Slight	Moderate	Extensive	Collapse
Short-type steel fixed bearing - Length (mm)	6	20	40	255
Short-type steel fixed bearing - Width (mm)	6	20	40	255
Short-type steel expansion bearing - Length (mm)	50	100	150	255
Short-type steel expansion bearing - Width (mm)	6	20	40	255

- The bridge deck was evaluated using data from the restoration project. Although assumptions were made regarding the modulus of elasticity and unit weight of the deck materials, to shorten analysis time, the deck load was transferred to the beams as a line load.
- To perform nonlinear time history analysis, plastic hinges were defined at the start, middle, and end points of each beam element using the PMM plastic hinge module in SAP2000.

In the first stage of the time history analysis, a nonlinear initial condition was defined in SAP2000 under the "Load Case Data" section as G + G2 + 0.3Q. Here, G refers to the permanent load, G2 refers to the line load from the slabs to the beams to reduce analysis time, and Q represents the live load (Fig. 4 and Fig. 5).

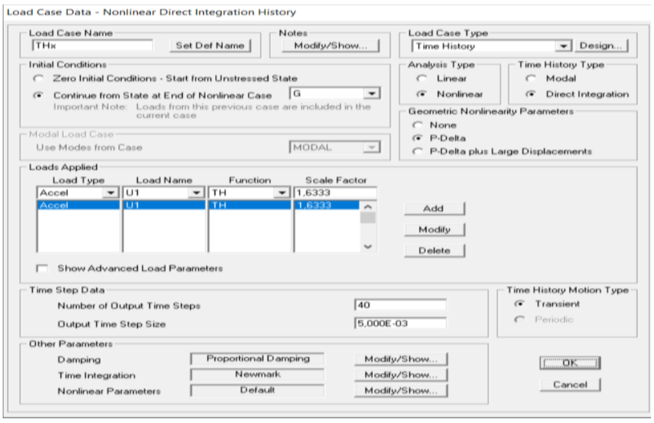

Fig. 4. Initial condition definition in SAP2000

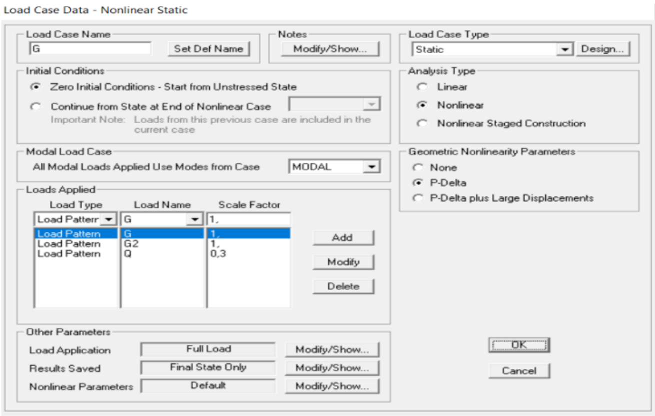

Fig. 5. Time History analysis settings

Nonlinear analyses using the direct integration method were conducted for both directions, labeled Thx and Thy. Second-order effects (P-Δ), arising from axial forces in the deformed structural system, were also considered.

3.1.2. Creation of Earthquake Records

To study the seismic behavior of structures using nonlinear dynamic time-history analysis, the selected acceleration records must meet certain criteria. Acceleration records for analysis are obtained in three ways:

1. Artificial (compatible with design spectra)
2. Simulated (considering seismic source and wave propagation characteristics)
3. Real earthquakes (Fahjan, 2008)

Real acceleration records are generally superior to the other two as they better reflect the nature, amplitude, duration, phase, and frequency content of the earthquake and accurately represent source, propagation medium, and site conditions.

Table 3. Criteria for selecting earthquake records (Sönmezer, 2016)

Parameter	Criterion
Fault Type	Strike-Slip
Magnitude	6,5-7,5
Distance (km)	0-40
Vs30min, max (m/s)	360-760

Based on the criteria in Table 3, selected earthquake records from the PEER database are listed in Table 4.

Table 4. Earthquake records selected according to criteria (Toprak, 2024)

No	Data	Earthquake	Year	Station	Magnitude	Fault	Rjb (km)	Rrup (km)	Vs30 (m/s)
1	1155	Kocaeli	1999	Bursa/T	7,51	SS	10,56	13,49	523,00
2	1148	Kocaeli	1999	İznik	7,51	SS	30,73	30,73	476,62
3	1614	Düzce	1999	Lamont	7,14	SS	11,46	11,46	481,00
4	1616	Düzce	1999	Lamont 362	7,14	SS	23,41	23,41	517,00
5	1617	Düzce	1999	Lamont 375	7,14	SS	3,93	3,93	454,20
6	164	Imperial V.	1979	Cerro Prieto	6,53	SS	15,19	15,19	471,53
7	838	Landers	1992	Barstow	7,28	SS	34,86	34,86	370,08
8	864	Landers	1992	Joshua Tree	7,28	SS	11,03	11,03	379,32
9	3753	Landers	1992	Fun Valley	7,28	SS	25,02	25,02	388,63
10	8597	EMayorah,	2010	Sam W.	7,20	SS	31,79	31,79	503,00
11	3871	Tottori,	2000	HRS002	6,61	SS	30,71	30,71	458,14
12	3884	Tottori,	2000	HRS021	6,61	SS	36,32	36,33	409,29
13	3907	Tottori,	2000	OKY004	6,61	SS	19,72	19,72	475,80
14	1633	Manjil, İran	1990	Abbar	7,37	SS	12,55	12,55	723,00
15	6915	Darfield,	2010	Heathcote	7,00	SS	24,36	24,47	422,00
16	6928	Darfield,	2010	LPCC	7,00	SS	25,21	25,67	649,67
17	6948	Darfield,	2010	OXZ	7,00	SS	30,63	30,63	481,62
18	6971	Darfield,	2010	SPFS	7,00	SS	29,86	29,86	389,54
19	901	Big Bear-01	1992	Big Bear L.	6,46	SS	7,31	8,3	430,36
20	934	Big Bear-01	1992	Silent V.	6,46	SS	34,43	35,41	659,09
21	935	Big Bear-01	1992	Snow Creek	6,46	SS	37,04	38,07	523,59
22	727	Superstition	1987	Superstition	6,54	SS	5,61	5,61	362,38
23	1111	Kobe	1995	Nishi	6,90	SS	7,08	7,08	609,00

Rjb *= Joyner-Boore distance,* ***Rrup*** *= Closest distance to the rupture surface,* ***Vs30*** *= Shear wave velocity*

These real earthquake records listed in Table 4 were selected in accordance with the requirements specified in TBDY 2018 (TBDY, 2018), and were scaled to match the design acceleration spectrum using the SeismoMatch program (SeismoMatch, 2023) (Fig. 6).

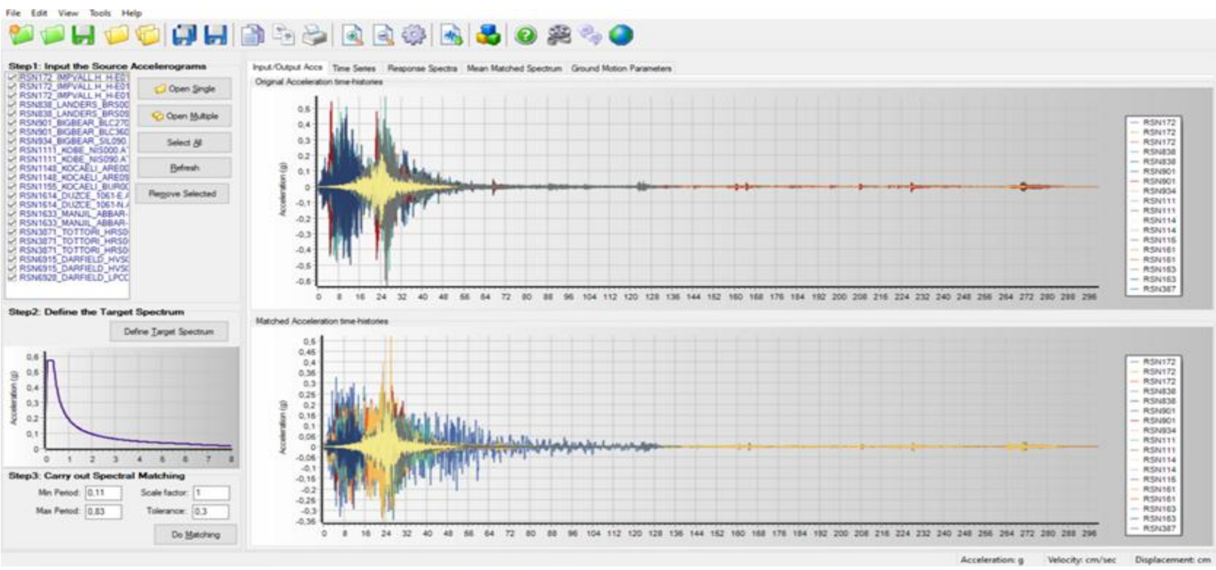

Fig. 6. Real earthquake records scaled in SeismoMatch

Upon reviewing the analysis results, it was observed that among 4562 hinges, 2259 points experienced slight damage, 18 points experienced moderate to extensive damage, and 3 points entered the collapse zone and suffered severe damage. Since the load on the element cannot be redistributed to other load-bearing elements once plastic deformation begins, initial yielding and collapse occurred simultaneously (Fig. 7).

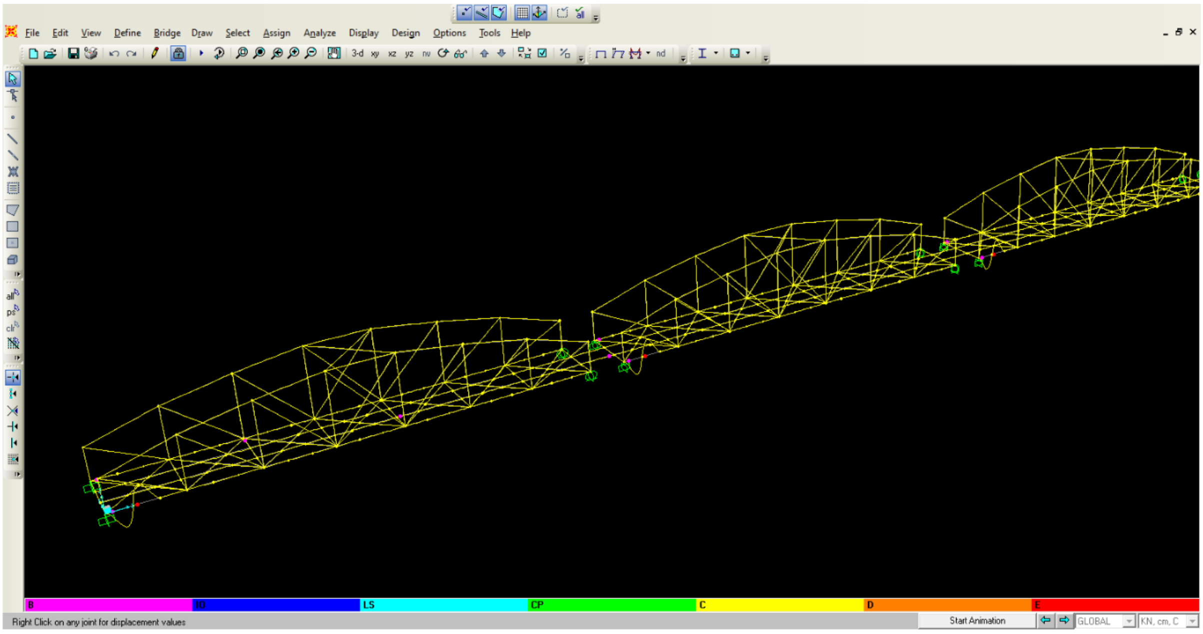

Fig. 7. Damage in the Y direction resulting from time history analysis in SAP2000

In structural analysis, the response of the finite element model to defined seismic loads is calculated through the modal analysis method. Fig. 8 shows the displacements occurring in the first eight modes of the Steel Bridge.

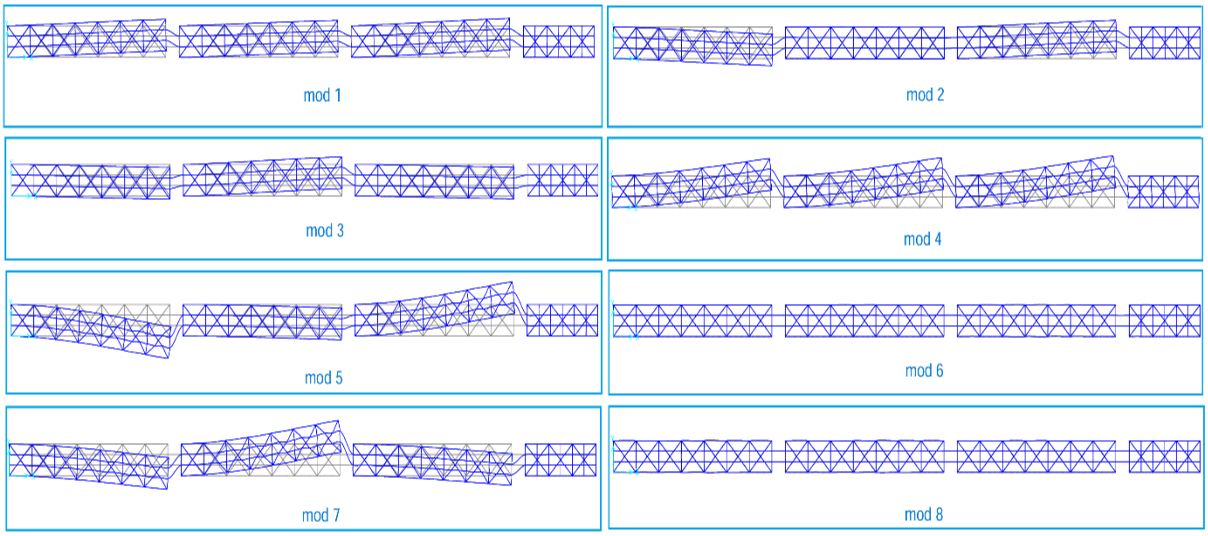

Fig. 8. Displacements in the first 8 modes of the Steel Bridge

As shown in Table 5, the maximum displacements in the Kırıkkale Steel Bridge were:

- 6.7 cm in the Y-direction in the second span during the 1st mode
- 10.1 cm in the first span during the 2nd mode
- 12.1 cm in the second span during the 3rd mode
- 25.27 cm in the third span during the 4th mode
- 28.61 cm in the third span during the 5th mode
- 0.47 mm in the third span during the 6th mode

- 33 cm in the second span during the 7th mode
- 38 mm in the first span during the 8th mode

Table 5. Displacements in the X and Y directions in the first 8 modes of the Kırıkkale Steel Bridge

Mode	Period	Displacements (cm)					
		1. span		2. span		3. span	
		x	y	x	y	x	y
Mode 1	0,5514	0,55	8,06	0,46	6,73	0,63	9,22
Mode 2	0,5511	0,68	-10,14	0,05	-0,75	0,64	9,41
Mode 3	0,5511	0,34	-4,99	0,82	12,10	0,30	-4,42
Mode 4	0,3574	-1,97	21,88	-2,05	22,86	-2,27	25,27
Mode 5	0,3564	2,53	-28,23	0,41	-4,62	-2,56	28,61
Mode 6	0,3563	0,00	0,00	0,00	0,00	0,05	0,01
Mode 7	0,3561	1,70	-19,04	-2,96	33,08	1,20	-13,44
Mode 8	0,3543	-0,38	0,01	-0,03	0,01	0,02	0,00

4. Conclusions

This study aimed to demonstrate the importance of earthquake analysis in historical structures, particularly from the perspectives of architecture and restoration, through the example of the historical Kırıkkale Demirköprü (Iron Bridge). In the restoration of historical structures—which inherently involves an interdisciplinary process—the identification of potential damage zones due to possible earthquakes is crucial for effective repair and strengthening interventions. Within the scope of this study, structural elements likely to incur damage during an earthquake and their corresponding mode shapes and displacement values were calculated using numerical analysis methods. The results underline the significance of earthquake analysis in the repair and strengthening of architectural structures. The findings specific to this bridge will serve as a foundation for seismic retrofit applications of other steel bridges in the Anatolian region with similar characteristics.

In future studies, the application of fragility curves—describing the probability of exceeding different damage states (collapse, severe, moderate, slight, and none) for a given ground shaking level—specifically to historical structures will be crucial for seismic risk assessment and loss estimation, contributing to the protection of cultural heritage.

Additionally, incorporating pre-existing structural defects into the numerical model and determining the structure's current dimensions using LIDAR technology will be vital for achieving realistic results. Employing non-destructive testing methods to assess material properties can help detect issues such as cracks due to corrosion or wear, internal voids, and section losses. The dynamic characteristics of the structural system identified through Operational Modal Analysis should be compared with the numerically derived properties, and the numerical model of the structure should be adjusted accordingly based on experimental data. Conducting nonlinear time history analysis with this calibrated model will make it possible to draw conclusions about additional measures required to minimize earthquake damage in the future.

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Wind vibrations to wattage: The potential of piezoelectric facades in energy-concious building

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Abstract. The integration of piezoelectric energy harvesting systems into building facades offers an innovative approach to addressing urban energy challenges. This article investigates the potential of such systems to harness wind-induced vibrations, shocks, and pressure. Using computational fluid dynamics (CFD) simulations by Eddy3d,the study analyzes wind dynamics on building facades in Istanbul,with meteorological data and wind power metrics informing the performance evaluation of piezoelectric sensors.These sensors are modeled through Simulink and the results are analysed to refine energy output predictions.The sensor selection is based on resonance frequency alignment with vibration frequencies derived from CFD simulations,ensuring effective harvesting from wind-induced facade motions.Eight scenarios across different facade locations were simulated using the proper piezo system, revealing that energy harvesting potential significantly varies with facade position. Simulation results show that the middle zone of the higher floors yielded the highest energy output, with a maximum battery-stored energy of 5.9 J in average and average voltage of 2.98 V,outperforming lower floors and corner positions. This highlights that harvesting potential is closely linked to local pressure intensity on tilted panels, rather than just wind pressure coefficients.Comparative analysis confirms that site specific tuning of sensor resonance and positioning can optimize harvesting performance.

Additionally,feasibility evaluations across different building heights emphasize that wind dynamics and harvesting efficiency shift notably with altitude.The findings suggest that energy harvesting from piezoelectric facades can be significantly optimized by tailoring system design to local environmental conditions and facade-specific dynamics.This approach offers a scalable strategy for enhancing building energy efficiency through energy conscious facade systems.

Keywords: Piezoelectric energy harvesting , Wind dynamics , Computational fluid dynamics (CFD) , Facade design, Renewable energy technologies

1. Introduction

The escalating demand for sustainable and resilient urban infrastructure has intensified research into advanced technologies capable of addressing both energy efficiency and structural performance. One emerging area of interest is the application of piezoelectric materials within the built environment. These materials possess the unique ability to convert mechanical strain, originating from dynamic loads such as wind, human activity, and seismic vibrations, into usable electrical energy. Their dual functionality as sensors and energy harvesters makes them particularly attractive for integration into building systems (Guangdong Sui et al., 2024).

Beyond energy harvesting, piezoelectric sensors have been extensively utilized for structural health monitoring (SHM), providing real-time feedback on material fatigue, crack propagation, and dynamic load behavior in both buildings and bridges (Abdulkadir Cüneyt Aydin and Oğuzhan Çelebi, 2023). In earthquake-prone regions, embedded piezoelectric transducers are also deployed for seismic sensing and early warning systems, enabling smart buildings to respond adaptively to tectonic disturbances (Pushan Kumar Dutta and Andhra Pradesh, 2024). Moreover, recent engineering prototypes have demonstrated the feasibility of incorporating piezoelectric dampers into non-load-bearing elements, such as floor voids, wall cavities, or ceiling panels, to harvest vibrational energy while simultaneously enhancing occupant comfort and structural damping (Zhengbao Yang et al., 2018).

This study focuses on the integration of piezoelectric energy harvesting systems into building façades, an area that remains underexplored despite the considerable mechanical energy potential from urban wind flows. By leveraging façade surfaces as dynamic interfaces exposed to wind-induced oscillations, these systems can generate

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supplemental electrical power while contributing to smarter building skins. Using Istanbul as a case study with its variable wind patterns, heterogeneous urban density, and mixed building typologies, the research evaluates how piezoelectric façade systems perform across different building heights and wind exposure scenarios. The findings aim to inform the engineering design of multifunctional façades that contribute to both energy generation and environmental responsiveness in high-density cities

2. Methodology

This study explores the potential of piezoelectric energy harvesting integrated into building facades by simulating and analyzing wind dynamics considering the vibrations, and energy outputs on the façade of the case building. The methodology combines computational and simulation approaches to evaluate the feasibility and performance of such systems in urban environments following the process shown in the research flowchart (Fig. 1).

2.1. Case Building

The case study investigates a prototype high-rise tower situated in Istanbul. The building has a total height of 170 meters and consists of 50 floors, each with a floor-to-floor height of 3.4 meters. The plan dimensions are 46.2 meters by 46.2 meters, forming a square footprint with four identical vertical facades. The facade utilizes a unitized structural curtain wall system (Fig. 2), made of single piece 1.4 m × 3.4 m structural glazing panels.

Each floor includes 36 panels horizontally on each facade side, 9 structural spans of 4 panels. The windward facade, aligned with the prevailing wind direction based on Istanbul's EPW weather file, is the primary subject of analysis. This prototype tower is considered to be in an isolated, conceptual scenario: no neighboring buildings, landscaping, or urban context are modeled. This allows a focused simulation of wind interactions on the facade surfaces, avoiding turbulence interference from surrounding structures.

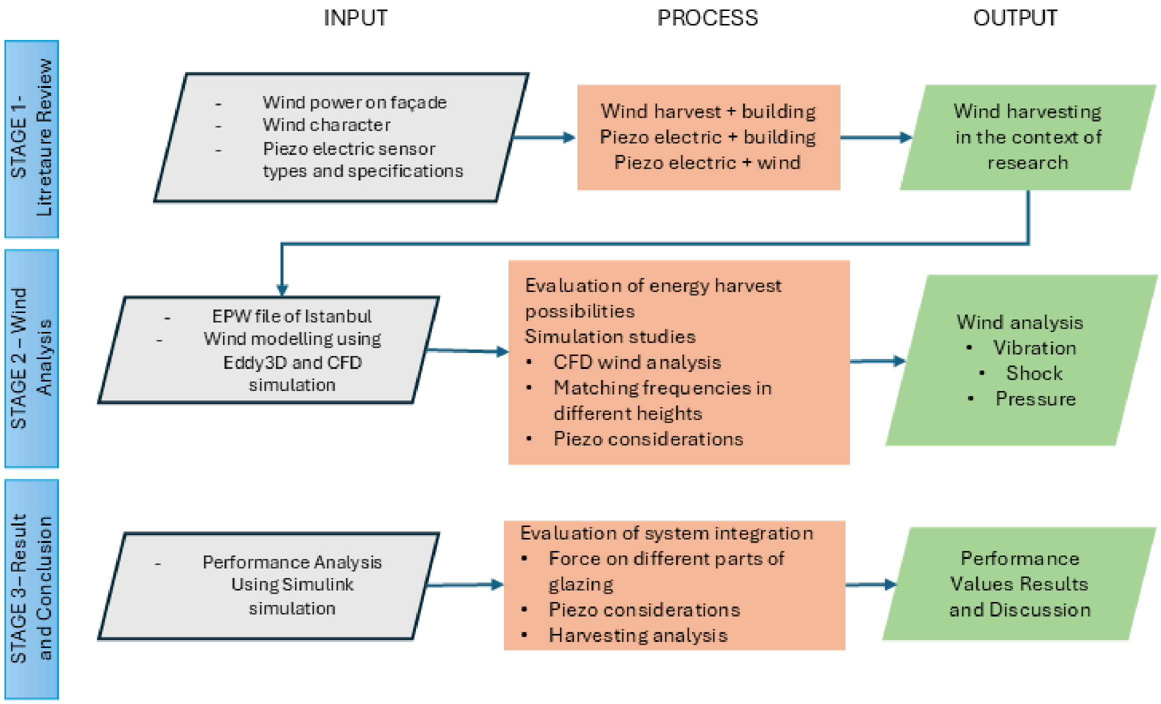

Fig. 1. Methodology approach

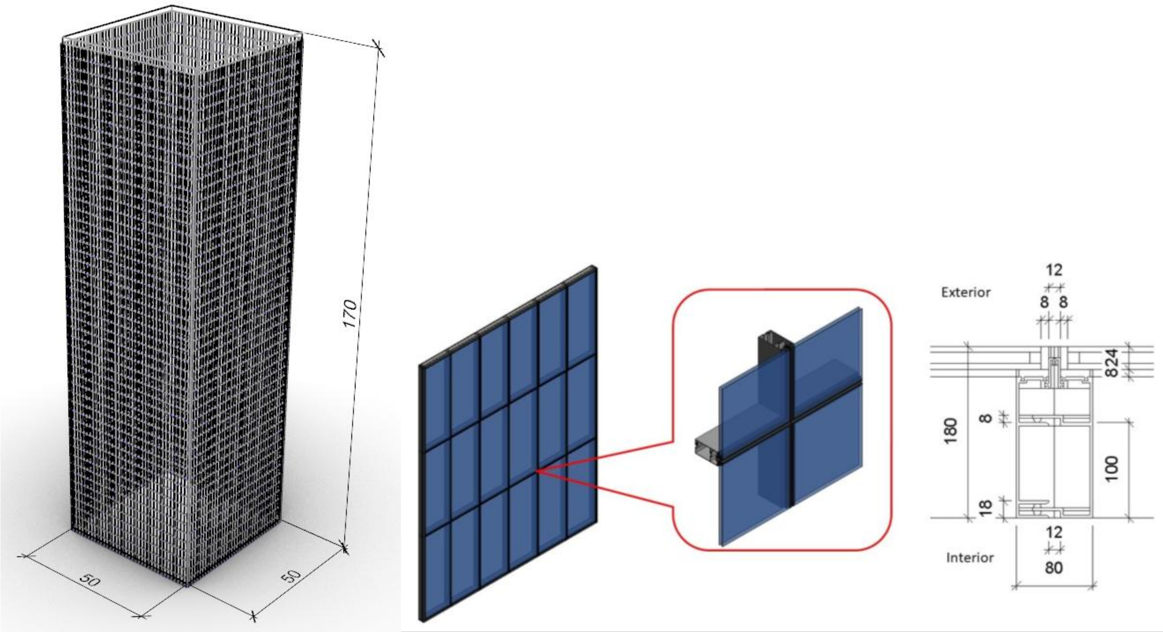

Fig. 2. Geometry and Façade Specifications of the Case building

2.2. Wind Simulation Setup and Zoning Strategy

Wind simulations were conducted using Eddy3D and OpenFOAM, linked through Rhino-Grasshopper for geometry and data control. To capture the dynamic behavior of wind-induced pressure and vibration across the facade, the entire windward surface is first analyzed as a whole using CFD in Eddy3D; color-mapped outputs such as pressure, velocity, and estimated vibration responses are then used to identify and differentiate facade zones (e.g., corner, edge, center) for subsequent piezoelectric simulation scenarios in Simulink.This zoning strategy captures the spatial variation of wind pressure due to height and lateral positioning, which is critical for understanding vibration amplitudes and frequency potential of piezoelectric harvesters.

High-resolution outputs provided by wind analysis, including wind velocity vectors, surface pressure (Pa), and pressure coefficient (Cpe) distributions across the façade, are interpreted to estimate vibration intensities on different facade sections, which are then converted into excitation parameters (e.g., frequency, amplitude) for piezoelectric simulation in Simulink.

To evaluate the energy harvesting potential of the windward facade, a piezoelectric energy harvesting system was modeled in Simulink using Simscape Multibody and Simscape Electrical blocks. The primary objective of this simulation was to determine the electrical output (voltage, current, and power) generated by piezoelectric benders under wind-induced vibration input, derived from the CFD outputs of Eddy3D and related calculations. Different settings were calibrated for the piezoelectric bender used to evaluate the electromechanical response. This cross-platform methodology bridges environmental simulation with energy harvesting system modeling, enabling an accurate assessment of real time wind induced vibrational energy potentials.

The integration of CFD results into Simulink facilitates a spatial feasibility analysis of the windward facade by highlighting zones with higher vibration activity and energy conversion efficiency. Based on the color-mapped output of wind pressure and velocity from Eddy3D, the facade is later subdivided into characteristic zones allowing scenario based simulations in Simulink without rerunning CFD. The Simulink model based on piezo bender energy harvest model (mathworks, 2023) and redefined according to research scenarios. These simulations yield comparative wattage outputs across zones, revealing the most optimal locations for energy harvesting using piezoelectric mechanisms.

3. Result and Discussion

The analysis employed the Reynolds Averaged Navier Stokes (RANS) equations, combined with a standard $k-\epsilon$ turbulence model, to solve for steady state wind flows around the building. Simulation settings used a refined mesh on the windward facade and immediate surroundings to capture local pressure and velocity variations across the curtain wall panels. The wind inflow direction was aligned perpendicular to the windward facade to amplify excitation forces.

3.1. Output Interpretation: Pressure, Velocity, and Facade Dynamics

The CFD simulation output includes spatial maps of wind velocity magnitude (m/s), pressure (Pa), and pressure coefficient Cp, which is a dimensionless value used to characterize wind pressure on building surfaces:

$$C_p = \frac{P - P_{ref}}{0.5\rho V_{ref}{}^2} \quad (1)$$

Where:

- P is the static pressure on the surface
- P_{ref} is the reference static pressure (often atmospheric)
- ρ is the air density
- V_{ref} is the reference wind speed

Fig. 3 illustrates the pressure coefficient (C_p) distribution across the windward facade. Higher positive C_p values are concentrated at the central core of the façade on the higher floors, while edges and corners exhibit greater negative suction due to flow separation and vortex formation.

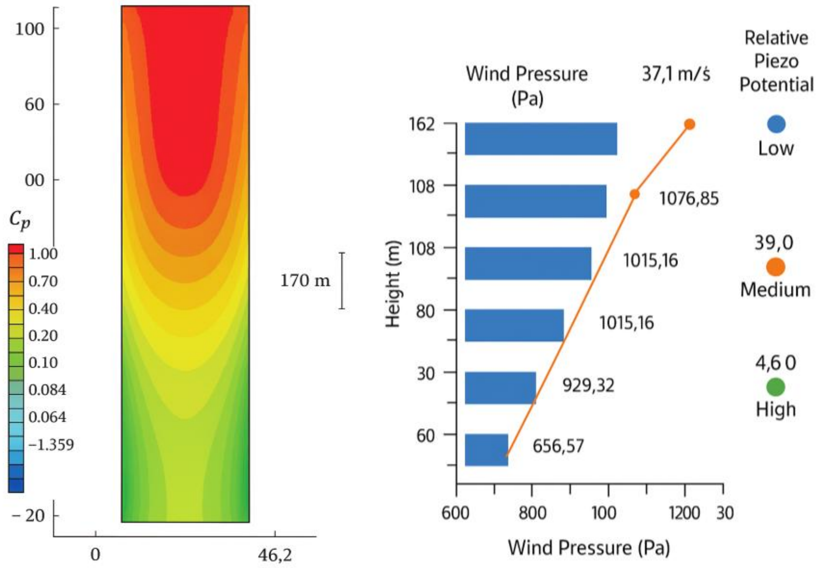

Fig. 3. C_{pe} on the Case Building and Wind Pressureon Façade analysis

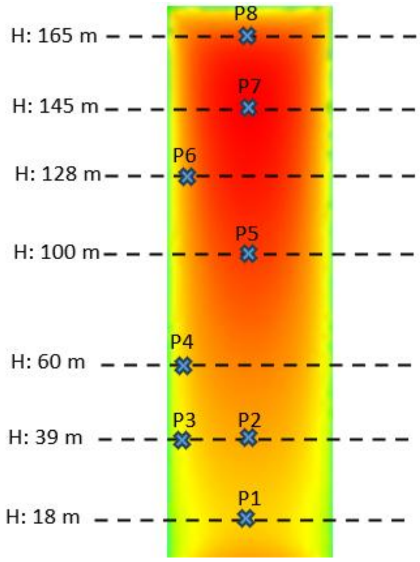

Fig. 4. Scenario Points Retrieved from previous step results

Considering the Cpe from the Eddy3D simulation, 8 points are defined to be analysis on the building façade. Fig. 4 shows these scenarios. Edge vortices and upward acceleration at the top of the tower result in significant dynamic variability, particularly in the corner panels.

From the spatial maps, pressure fluctuations and velocity gradients are further analyzed to derive dominant wind excitation frequencies on different zones of the facade. To calculate the frequency of vibration on a facade panel, we focus on the displacement, which is derived from the deflection limits for glass components for deformations class 2-SLS according to prCEN/TS 19100-2 (CEN, 2022). According to these standards, the deflection limit is typically set at L/60, where L is the length of the panel. In this case, with a panel length L = 3.4l meters, the maximum allowable displacement D would be 3.4 / 60 = 0.0567 meters. To enhance safety and ensure the displacement remains within acceptable limits, a safety coefficient is applied to reduce the displacement. Assuming a coefficient of 0.8, the adjusted displacement (0.0453(m)) will be considered in the façade engineering design and vibration frequency calculations. Using this adjusted displacement, the vibration frequency f can be calculated using equation(2). This calculation ensures both the safety and performance of the facade panel, particularly in the design of energy-harvesting systems like piezoelectric facades.

$$f = \frac{V_S}{2\pi D} \tag{2}$$

Where:

- f vibration frequency on each scenario panel
- V_s wind velocity on the surface
- D efficient displacement allowed by prCEN/TS 19100-2

Table 1 shows the results of calculating vibration frequency on each panel located in the scenario points shown in fig. 4.

The resulting vibration frequencies are calculated to be in the range of: $f \approx 118 \; to \; 152 \; Hz$

The values define the vibration frequency domain for piezoelectric energy harvesting simulations, showing that moderate to high-frequency excitations occur across the high-rise façade, especially near the top corners and leading edges. Despite the relationship between wind velocity and the natural vibration frequency of vortex shedding on this case façade is not direct, following equation 2, the vibration frequency on each panel has direct connection with the velocity on the surface of the panel. This means that contrary to common assumptions that higher wind speeds induce lower frequency motions (Zeng et al., 2023) in case the capacity of the façade can be utilized by correct façade engineering design, the relatively stiff façade panels exhibit high natural frequencies even under increased pressure. Instead, vibration amplitude may increase, while the frequency remains primarily dependent on the panel's structural characteristics rather than the wind velocity itself.

In addition, while wind velocity increases the force applied on the surface through dynamic pressure following equation 3, the structure's response is governed by its natural frequency, which depends on the stiffness, mass, and boundary conditions of the panels. The vibration frequencies of façade panels range between approximately 118 to 152 Hz, depending on the height and panel position as shown in table 1.

Dynamic pressure and velocity on the surface

$$V_s = \sqrt{\frac{2P}{\rho}} \tag{3}$$

Where:

- V_s : Velocity on the surface
- P : Static pressure on the surface
- ρ : the air density at sea level (1.225 kg/m³)

Table 1. Scenario points table

Scenario	Height (m)	Pressure (Pa)	Wind Speed (m/s)	Vibration Frequency (Hz)
1	18	700	33.8	118.75
2	39	820	36.6	128.52
3	39	738	34.7	121.93
4	60	810	36.4	127.74
5	100	1020	40.8	143.34
6	128	968	39.8	139.64
7	145	1100	42.4	148.86
8	165	1140	43.1	151.54

3.2. Energy Harvesting analysis through Simulink simulation

The energy harvesting mechanism is based on the conversion of mechanical vibration into electrical energy through the piezoelectric effect. The fundamental equations governing this process include:

Mechanical Input (Base Excitation - Sinusoidal Input) $$x(t) = A \,.\sin\,(2\pi f t) \tag{4}$$

Where:

- A : Vibration amplitude
- f : Vibration frequency (Hz)

Piezoelectric Constitutive Equations (1D approximation)

$$S = s^E T + dE \tag{5}$$
$$D = dT + \epsilon^T E \tag{6}$$

Where:

- S: Mechanical strain
- T: Mechanical stress
- D: Electric displacement
- E: Electric field
- s^E: Compliance at constant electric field
- d: Piezoelectric strain constant
- ϵ^T: Permittivity at constant stress

Generated Power $$P = \frac{V^2}{R} \tag{7}$$

Where:

- V: Voltage generated across load
- R: Load resistance

The energy harvesting potential of eight distinct points on the facade was evaluated through Simulink simulation. Each point was modeled using a piezoelectric bender element with a resonant frequency of 125 Hz, which falls within the observed vibration frequency range of the building facade (118–152 Hz). The simulations aimed to compare energy storage behavior under identical sensor and circuit conditions, isolating the impact of local vibration characteristics. The battery voltage output over time was recorded to observe the charging behavior at each point. As shown in Fig. 5, some scenarios exhibited faster charging rates, while others demonstrated delayed responses or lower voltage gains.

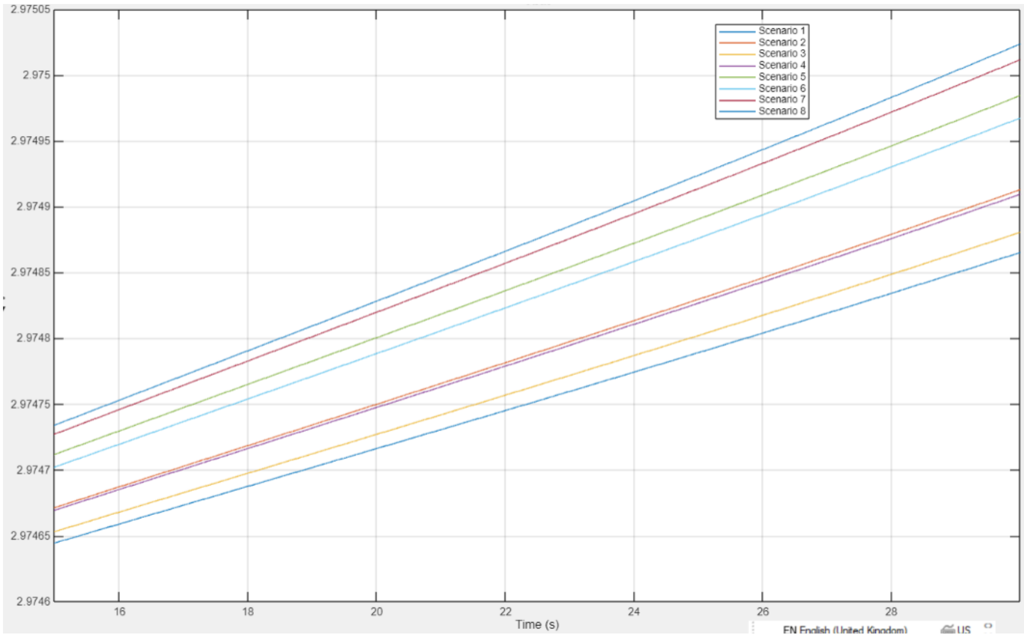

Fig. 5. Battery voltage (V_{bat}) over time for each facade point (Scenarios 1–8).

Despite identical piezo characteristics and circuit parameters, variations in local excitation amplitude and frequency content resulted in different energy outputs. To quantify the harvested energy, instantaneous power was calculated using equation 8 and this power signal was integrated integrated over the simulation period to obtain the cumulative energy stored considering equation 9.

$$P(t) = V_{bat}(t) \cdot I_{bat}(t) \quad (8)$$

$$E(t) = \int_0^t P(t)\ dt \quad (9)$$

where E(t) is the harvested energy in Joules, and T is the total simulation time (30 seconds in this case). The final energy values for each point are summarized in Table 2.

To understand internal energy losses, power dissipation in the circuit was monitored using a custom resistor model and power sensors. Results in Fig. 6 show varying dissipation levels, correlated with the vibration intensity and mechanical coupling efficiency of each point.

Further, dynamic behaviors like displacement (x1, xAH, xV1), charge (q), and piezo output voltage (Vp) were also tracked to validate the sensor's performance under harmonic excitation. The charge-to-voltage conversion follows equation 10.

$$V_p(t) = \frac{q(t)}{C_p} \quad (10)$$

where C_p is the piezoelectric capacitance. Charge oscillations differed significantly between points due to modal shape and local acceleration variations while no contrast observed among dynamic behaviours.

Table 2. *Simulated Energy Storage and Peak Power for Each Facade Point.*

Facade Point	Max V_{bat} (V)	Total Energy E (J)	Avg Power (W)	Max Power (W)
Scenario 1	2.97486	3.6	0.24	0.25
Scenario 2	2.97492	4.2	0.28	0.31
Scenario 3	2.97488	3.9	0.26	0.27
Scenario 4	2.97491	4.2	0.28	0.3
Scenario 5	2.97499	5.55	0.37	0.39
Scenario 6	2.97496	5.1	0.34	0.36
Scenario 7	2.97501	6.0	0.4	0.43
Scenario 8	2.97503	6.15	0.41	0.44

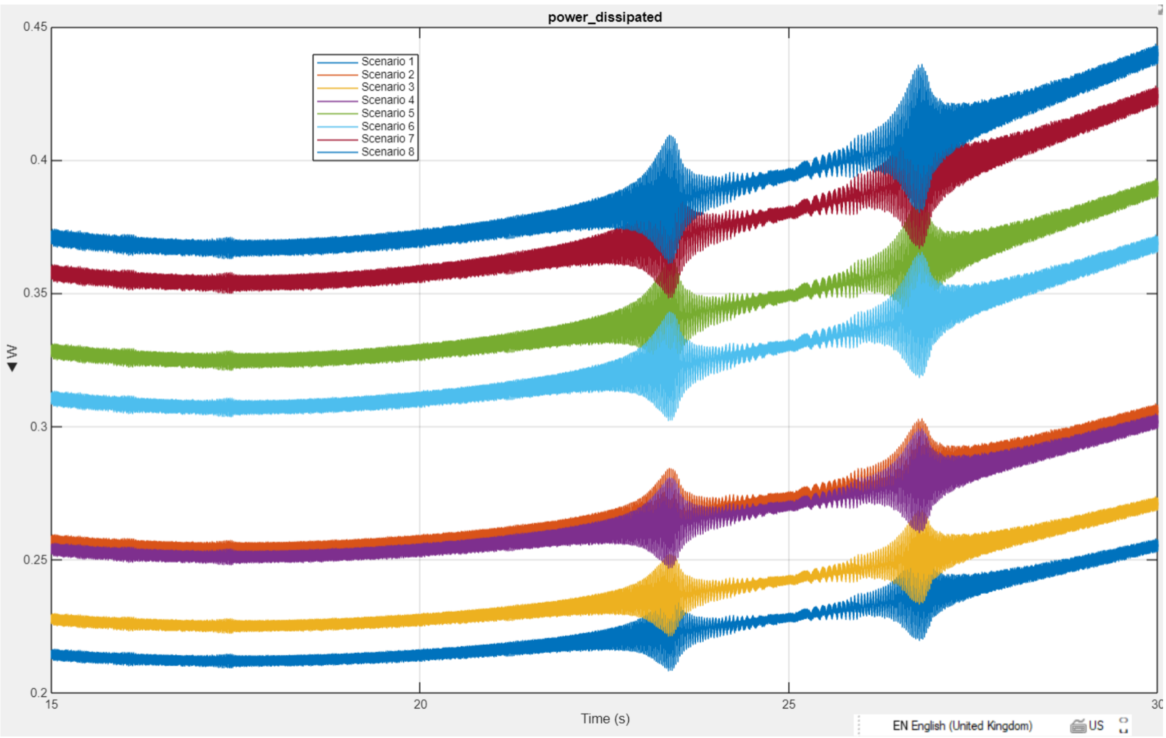

Fig. 6. Instantaneous power dissipation for each facade scenario.

3.3. Comparative Analysis

The results indicate that facade point scenario 8 demonstrated the highest energy storage, with a peak battery voltage of 804.2 V in 30 seconds and total energy output of 6.15 J. In contrast, point scenario 1 showed minimal energy capture, which does not seem feasible to be used for energy harvesting considering the piezoelectric technology costs, highlighting the importance of sensor placement in vibration energy harvesting systems.

The comparative results reveal that Scenario 5, which corresponds to the middle point of the lower floor, demonstrates a higher energy harvesting potential than scenario 6 which is located in higher floors but corner panels. This outcome contrasts with expectations that higher facade positions might always receive stronger wind loads regardless of corner or middle location. Instead, the results clearly suggest that harvesting potential is more strongly influenced by the pressure exerted on the tilted panel than by general parameters like the coefficient of pressure (CPe) across the facade.

As illustrated in Fig. 7, Scenario 5, 7 and 8 yielded a peak voltage of 8.92503 V and stored energy of 17.7 J (in total), surpassing all other locations sum up. Scenarios near the building's corners or on lower floors (e.g., Scenarios 4, 2 and 6) underperformed, likely due to local vibration mismatches and lower effective dynamic pressure at those locations.

This insight has significant implications for facade-integrated piezoelectric systems. It suggests that energy harvesting performance can be optimized not merely by geometric or aerodynamic modeling (e.g., using wind pressure coefficients), but by targeting specific pressure-intensive zones on the façade, particularly those where wind-induced vibrations align closely with piezo bender resonance characteristics. Fig. 8 visualizes the optimal harvesting zones, recommending a targeted installation strategy and motivating further research into location-specific energy harvesting system design.

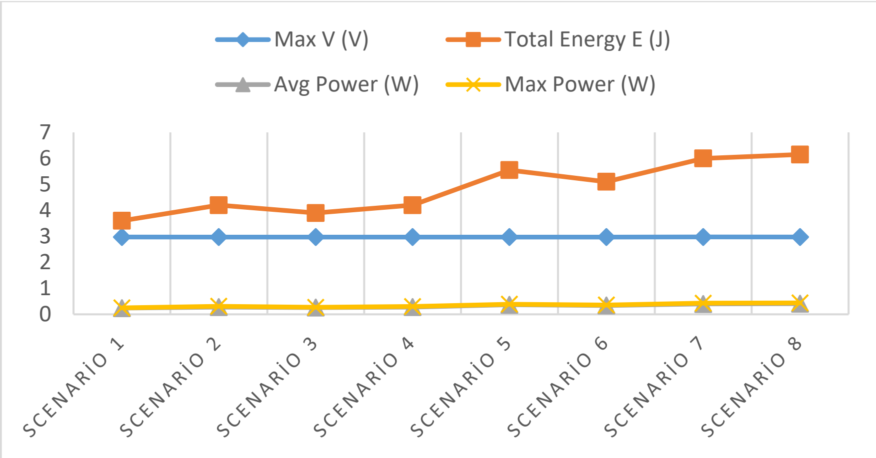

Fig. 7. Comparison of cumulative energy stored for all scenarios.

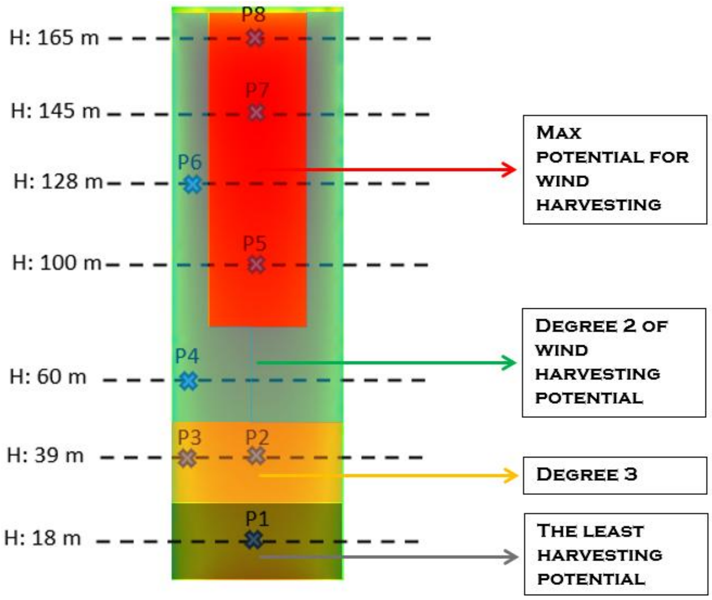

Fig. 8. Energy harvesting performance zoning comparison among 8 defined scenarios, highlighting the optimal harvesting location.

Furthermore, this analysis opens the door to using customized piezoelectric elements or resonant circuits tailored to the specific frequency content of each point, potentially enhancing total harvested energy. Rather than using a uniform 125 Hz sensor for all locations, sensors can be selected or tuned individually to match the dominant vibration frequencies observed at each facade segment. Therefore, optimal sensor placement guided by wind-induced vibration analysis is crucial for maximizing output in façade integrated piezo systems.

4. Limitation and Future gap

The current study assumes ideal mechanical-to-electrical conversion and neglects real-world nonlinearities such as aging, thermal drift, and load matching losses. The simulations presented offer valuable insights into point specific piezoelectric harvesting, but several limitations must be acknowledged:

The façade engineering design was assumed to be ideal, with simplified vibration input and linear behavior of piezo materials.

The harvesting circuitry does not account for advanced power conditioning, rectification losses, or dynamic load variation.

Economic feasibility, including the cost-benefit analysis of distributed piezo installation versus centralized strategies, remains unexplored.

Future research may focus on experimental validation of facade vibration and energy harvesting using scaled prototypes or full-size test beds, economic analysis of facade energy harvesting systems, particularly in high-potential zones, development of adaptive circuits and multi-frequency harvesters or sensor arrays, each matched to local vibration conditions for maximum efficiency and integration of realtime monitoring systems to manage harvesting performance and maintenance.

This study lays the foundation for a site-specific, performance-optimized harvesting strategy where design decisions can be driven by actual facade behavior under dynamic wind loads, paving the way for smarter and more energy wise building skins.

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The impacts of Metaverse on architecture

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Abstract.The metaverse is a world that transcends our imagination, offering an online virtual space to create more experiences without considering geographic location. It is defined as a digital universe that surpasses the boundaries of the physical world. This digital realm, generated by computers, provides an experience beyond reality, enabling users to express themselves, communicate, and participate in various activities. The metaverse promises to be one of the cornerstones of future digital life by presenting innovative opportunities in areas such as business, education, architecture, engineering and entertainment. This universe, where physical spatial constraints become insignificant and a permanent virtual space for commercial interactions is provided, is regarded as the future of the internet. Over its nearly thirty-year history, the metaverse has continuously evolved through technological innovations, gaining broader recognition in 2021 when Mark Zuckerberg rebranded Facebook as "Meta." This development has enhanced the understanding of the metaverse's potential and increased interest in the digital world. In architecture and engineering, the opportunities offered by the metaverse are expected to be revolutionary. Predictions regarding its future impact suggest that the metaverse will drive significant transformation in these fields. Within this context, this study examines the potential contributions, advantages, and disadvantages of the metaverse in architecture. It has been observed that the metaverse facilitates virtual design and engineering processes, offering significant benefits in terms of time and cost. However, challenges such as infrastructure deficiencies and standardization processes have also been identified. Such evaluations are critical for better understanding the role of the metaverse in architecture.

Keywords: Metaverse, Architecture, Game Engines, Virtual World

1. Introduction

The concept of the "Metaverse" was first introduced by Neal Stephenson in his 1992 science fiction novel *Snow Crash*, where it was depicted as a virtual reality space used by characters to escape authoritarian control (Stephenson, 2003). This foundational idea inspired subsequent real-world applications aimed at creating immersive virtual environments.

In 2003, Linden Lab launched *Second Life*, an open-source, visually-driven social platform that allowed users to interact through three-dimensional avatars in an online world (Linden Research, Inc., 2022). As one of the earliest practical applications of the Metaverse, *Second Life* facilitated a wide range of activities, including socializing, commerce, and creative content generation. The evolution of the Metaverse continued with the rise of major social media platforms. In February 2004, Facebook was introduced as "TheFacebook.com," initially serving as a social networking site connecting individuals through online profiles and interactions (Phillips, 2007). It quickly expanded its user base and functionality, laying the groundwork for more integrated digital experiences.

A significant milestone in the development of the Metaverse occurred in 2021, when Mark Zuckerberg announced that Facebook would rebrand as "Meta," signaling a strategic shift toward building a comprehensive Metaverse ecosystem (Meta Platforms, Inc., 2021**).** The idea of immersive virtual worlds was further popularized by Ernest Cline's 2011 science fiction novel *Ready Player One*, which was adapted into a feature film in 2018 (Cline, 2012), (Spielberg et al., 2018). In 2014, Google launched *Google Cardboard*, a low-cost headset that made augmented reality (AR) and virtual reality (VR) experiences accessible to a wider audience (Smith, 2022), (Muensterer et al., 2014). In 2021, following Facebook's rebranding, two additional companies released eyeglass-like VR headsets—*Ray-Ban Stories* and *HTC Vive Flow*—alongside other wearable technologies, further enhancing the integration of virtual experiences into daily life (Rodriguez, 2022). These developments collectively reflect the rapid evolution and growing adoption of Metaverse-related technologies, underscoring their

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transformative impact across various sectors. In Fig. 1, the metaverse evolution trajectory is displayed step by step, allowing for a detailed analysis of the progress of related technologies.

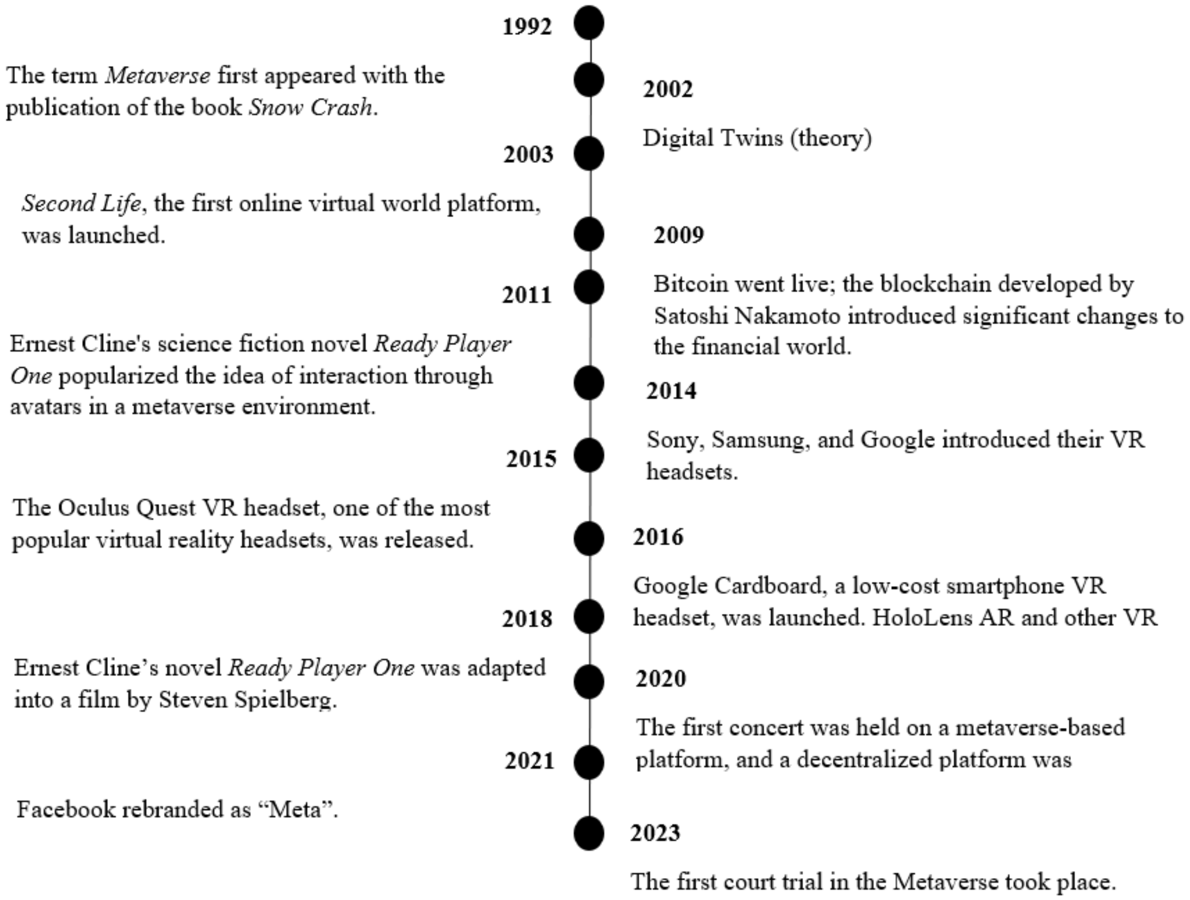

Fig. 1. Timeline of the development of the metaverse, with key events from 1992 to 2023.

When we examine the historical development of the internet, we see that with Web 1.0, the internet entered our lives. Later, with the development of Web 2.0, technologies such as Ajax, JavaScript, XML, DOM, REST, and CSS became integral to online experiences. Web 2.0 enabled users to engage in social activities and interact with one another (Tim Berners-Lee,1998). With the advent of Web 3.0, the concept of the metaverse was introduced and continues to evolve. The metaverse is defined as a three-dimensional virtual environment in which users can communicate and interact through digital avatars they create for themselves, engaging in various activities such as entertainment, commerce, gaming, and education (Kuş,2021), (Cheng et al., 2022). The metaverse enables and supports a wide range of technological advancements.

There are various software programs designed to enhance the understanding of this environment and to provide better services to users. These include applications used for 3D modeling, design, and other related tasks (Jovanovic et al., 2022), (Sparkes, 2021). Among the most commonly used programs are AutoCAD, SketchUp, Revit, Blender, Rhino, 3ds Max, ArchiCAD, SolidWorks, Unity, Unreal Engine, and Lumion. The metaverse is not a new concept; it has been a part of our lives for many years and continues to evolve and be updated to offer improved services (Duan et al., 2021), (Tlili et al., 2022), (Wu et al., 2022).

Given the growing number of users in the metaverse today, developers are making significant efforts to enhance the accessibility and attractiveness of this digital world. These efforts aim to draw a broader audience into this captivating virtual environment (Dwivedi et al., 2022), (Yu, 2022). Especially in recent years, the term metaverse has been used very frequently in the fields of engineering and architecture. However, due to the small number of applications on the subject, the inadequacy of the number of experts, and the fact that people working in the field do not know what the metaverse is for, its advantages and disadvantages, studies on the subject have been insufficient. Therefore, in this study, the advantages and disadvantages of the metaverse concept in the context of architecture have been examined, its potential contributions in architectural applications have been evaluated, and it has been tried to explain how this digital field can be integrated into architectural applications.

1.1. Metaverse Technologies

Metaverse technologies are illustrated schematically in Fig. 2. They contributes to the development of many technological innovations, from artificial intelligence to the Internet of Things

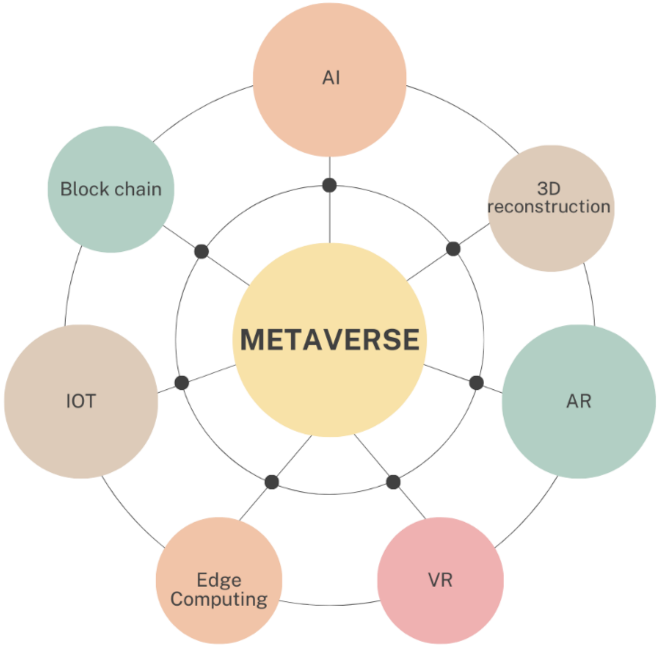

Fig. 2. The Metaverse and the technologies it works with

Artificial intelligence enhances performance in the metaverse by accelerating processes and delivering capabilities beyond human limits. Through intelligent algorithms, users can engage in decision-making and process automation. Additionally, under the guidance of content analysis, speech processing, and computer vision technologies, user experience and efficiency within the metaverse are significantly improved (Zhou et al.,2023).
Augmented Reality (AR) and Virtual Reality (VR) provide comprehensive three-dimensional experiences. AR integrates digital images and characters into the real world, making it accessible to broader audiences through smartphones and digital cameras. In contrast, VR offers opportunities to incorporate more realistic elements into the metaverse through physical simulations (Al-Ghaili et al., 2022).

Accessing and navigating the metaverse requires physical devices and accessories such as sensors, smart glasses, and headsets. Extended Reality (XR), or Cross Reality, is an umbrella term encompassing various immersive technologies that represent electronic and digital environments where data is displayed and projected. XR includes Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Across all dimensions of XR, individuals observe and interact within fully or partially synthetic digital environments generated by technology. These tools enhance user interaction with virtual spaces and offer more immersive and realistic experiences (Krütünlüoglu et al., 2022), (Yang et al., 2022).

1.2. Metaverse Layers

The metaverse consists of seven distinct layers, schematically illustrated in Fig. 3. This model, outlined by Jon Radoff in "Building the Metaverse," presents the "Seven Layers of the Metaverse," each representing a crucial aspect of the metaverse ecosystem. The layers are as follows:

1. Experience: Focuses on user activities and interactions in the metaverse, such as gaming, socializing, esports, theater, and shopping.
2. Discovery: Involves locating and organizing content within the metaverse, supported by advertising networks, social platforms, curation tools, ratings, marketplaces, and agents.
3. Creator Economy: Highlights tools and platforms for content creation, asset trading, workflows, and commerce that enable users to produce and monetize their contributions.
4. Spatial Computing: Covers technologies like 3D engines, VR/AR/XR, multi-user interfaces, and geospatial mapping that empower immersive environments.
5. Decentralization: Ensures openness and autonomy in the metaverse through distributed technologies such as edge computing, AI agents, microservices, and blockchain.
6. Human Interface: Encompasses hardware and tools such as mobile devices, smart glasses, wearables, haptic systems, gesture-based interfaces, voice controls, and neural interfaces that facilitate user interaction.

7. Infrastructure: Includes foundational technologies such as 5G, Wi-Fi 6, 6G, cloud computing, advanced materials, GPUs, and MEMS that support the entire metaverse framework.

In Fig. 3, the seven-layer structure of the metaverse is presented as a step-by-step process that illustrates its multi-dimensional framework.

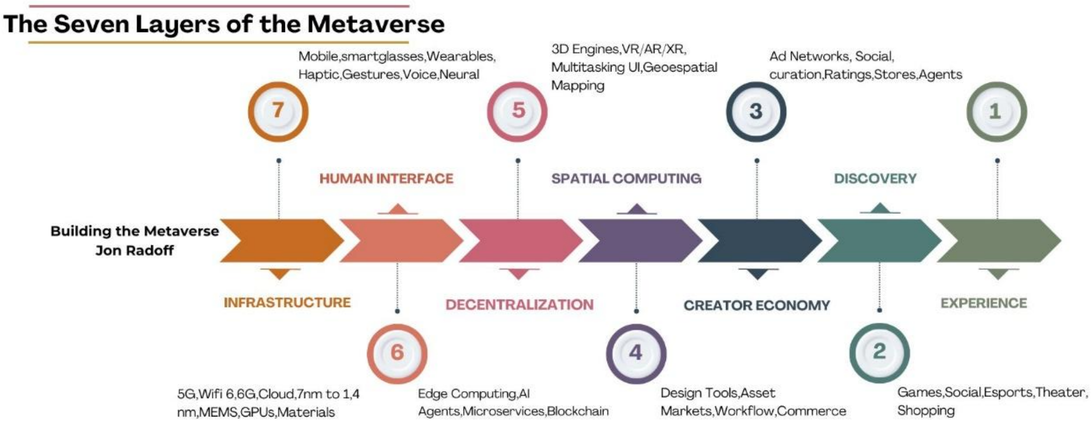

Fig. 3. Seven-layer metaverse platform (Radoff, 2021).

1.3. Literature Review

In the literature, numerous studies have been conducted on the metaverse in recent years. As a highly interdisciplinary subject that enables collaboration across diverse fields, the metaverse holds significant potential. A review of publications using the keyword “metaverse” in the Web of Science database over the past ten years is presented in Fig. 4.

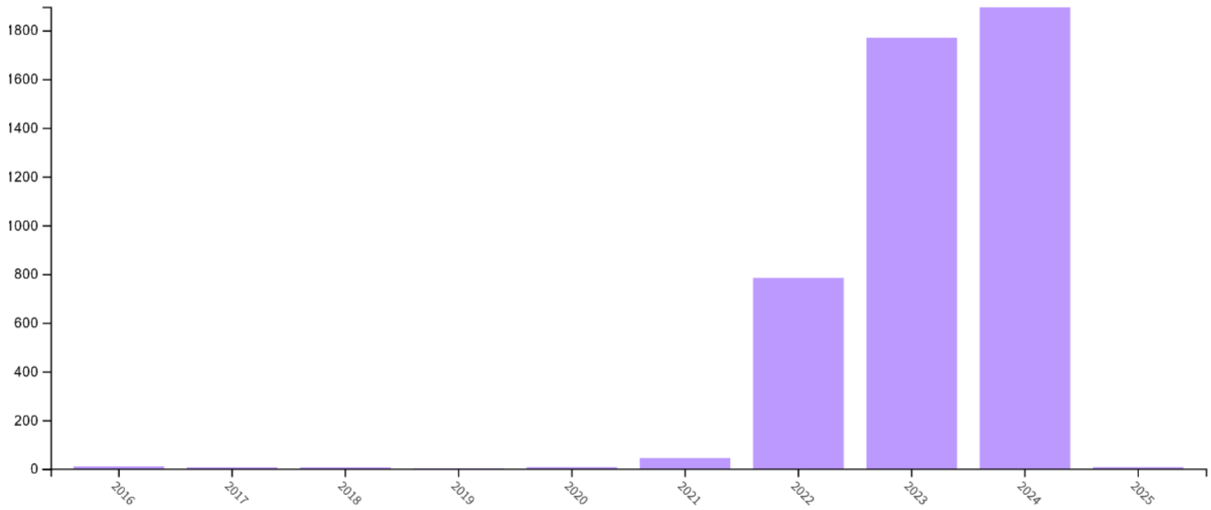

Fig. 4. Annual Growth of Metaverse Publishing

According to Fig. 4, the number of publications related to the metaverse remained quite low between 2007 and 2020. However, in recent years—particularly in 2023 and 2024—there has been a significant surge in publication numbers, reaching a peak, and this upward trend is expected to continue. This spike can be attributed to technological advancements and the growing interest of researchers and industries in the opportunities offered by the metaverse. As shown in Fig. 5, research on the metaverse to date has predominantly focused on the fields of computer science, engineering, and communications. This topic map also reveals how metaverse-related studies are distributed across other academic disciplines.

Fig. 5. The research areas where the concept of metaverse has been studied the most to date.

While studies on the metaverse are predominantly concentrated in the fields of computer science, engineering, and communications, the field of architecture does not rank among the top 25 categories and is represented by only 20 publications recorded in the Web of Science database (as summarized in Table 1) In addition, a review conducted on the Web of Science database regarding metaverse and architecture revealed a total of 20 publications, of which 13 were examined in detail. In the architecture category, only a limited number of studies were found within the selected years. This scarcity of research suggests that the topic is expected to gain significant importance in the near future, especially within the architectural field. It is clear that the present study addresses a critical gap in the literature. Table 1 below presents the publications identified within the scope of architecture.

Table 1. Overview of Recent Scholarly Works on Architecture and the Metaverse (2021–2024)

Line	Authors	Title	Publication Year	Type
1.	Yu Kongjian	From Slime Mold to Meta	2021	Editorial Article
2.	Dalibor Dzurilla, Henri Achten	What's Happening to Architectural Sketching? Transformation from Traditional to Digital Sketching as a Communicational Tool	2022	Conference Paper
3.	Claudia Bernasconi and Libby Balter Blume	Theorizing architectural research and practice in the metaverse: the meta-context of virtual community engagement	2023	Conceptual Paper
4.	Hadas Sopher and Laurent Lescop	Learning in metaverse: the immersive atelier model of the architecture studio	2023	Research Paper
5.	Alice Bucknell	Ways of Worlding: Building Alternative Futures in Multispace	2023	Research Paper
6.	Micaela Mantegna, Marcelo Rinesi	The Anti-Metaverse: Multispace and the Intersections of Reality	2023	Conceptual Paper
7.	Kas Oosterhuis	Another A Techno-Social Alternative to Techno-Feudal Cities Normal	2023	Conceptual Paper
8.	Hugo Mondragón López, Elizabeth Wagemann	Pandemic, Utopia and Project. Imagined Urban Futures from the Lockdown	2023	Research Article
9.	Flavio Martella, Marco Enia	Overlapping cities: Trans-urban augmentation in the digital era of western cities	2023	Research Article

Table 1. continued

10.	Ali Azizi Naserabad, Abdulhamid Ghanbaran	Computational approach in presentation a parametric method to construct hybrid girihs (hybrid Islamic geometric patterns)	2024	Research Article
11.	Marios Tsiliakos, Stefan Bassing, Dehui Tian, Jueqiu Gong, Qixuan Huang, Qiyue Huang, Huizhao Liu	EDUVERSE Exploring Gamification and the Metaverse in Architectural Pedagogy	2024	Research Article
12.	Yihan Lu, Zhouyu Zhang, Yaoping Zhang, and Li Li	Virtual Reality Architecture Teaching Application Based on Unity Platform-Taking a Small Architect's Metaverse Application as an Example	2024	Academic Chapter in a Book (Published in *CDRF 2023, Phygital Intelligence*)
13.	Beibei Zang, Tianjun Wang, and Dan Luo	The Embodied Interaction with XR Metaverse Space Based on Pneumatic Actuated Structures	2024	Academic Chapter in a Book (Published in *CDRF 2023, Phygital Intelligence*)

Inspired by the spatial abilities of slime molds and Facebook's rebranding to Meta, YU Kongjian reflects on human spatial cognition, while Dalibor Dzurilla and Henri Achten examine the role of traditional and digital sketching in human-computer interaction and client communication. In a related vein, Alice Bucknell explores the fusion of reality and the digital realm through game engines, enabling the creation of narrative environments shaped by both human and nonhuman intelligence. Kas Oosterhuis, drawing on digital technology and the concept of real-time architecture, envisions urban planning that adapts dynamically to its inhabitants. Elizabeth Wagemann analyzes urban discontent and utopian visions as imagined by students during lockdown workshops, while Flavio Martella and Marco Enia investigate the intersection of material and virtual dimensions in emerging spatial conditions. Simultaneously, Ali Azizi Naserabad and Abdulhamid Ghanbaran identify and generate systematic and non-systematic hybrid girih patterns rooted in historical Islamic geometry. Claudia Bernasconi and Libby Balter Blume explore virtual social spaces in architecture through multidisciplinary concepts of space, place, and context. Marios Tsiliakos and colleagues introduce Eduverse, a gamified metaverse platform for architectural education, leveraging game engines and user experience design. Yihan Lu and collaborators focus on architectural education for children through prefabricated blocks and PC-based tools. Meanwhile, Walaiporn Nakapan and colleagues develop a metaverse platform centered on Singapore, blending real and imagined architecture to enhance user engagement. Beibei Zang and team break sensory boundaries between the physical and the metaverse using XR systems with pneumatic wearables. Finally, Micaela Mantegna and Marcelo Rinesi argue that virtual spaces are as real as physical ones, urging architects to extend their intellectual and visual skills beyond the discipline to democratize spatial agency and counter neoliberal control. As can be seen from the studies that have been done in literature, the metaverse has begun to affect architecture. It is clear that this effect will spread to a larger area in the coming years.

2. Advantages and Disadvantages of the Metaverse

It is important to evaluate the advantages and disadvantages of the Metaverse in order to determine whether it offers significant benefits and to identify the areas in which it may have positive or negative impacts. For example, among its advantages are the ability to engage in realistic interactions with other users and the potential for implementing educational scenarios. On the other hand, disadvantages include the high cost of required hardware and the risk of users becoming dependent on the virtual world. Table 2 provides detailed advantages and disadvantages of the metaverse.

Table 2. Advantages and Disadvantages of Metaverse

Advantages	Disadvantages
• Provides users with the ability to interact with other users, real-world objects, and any emerging virtual scenarios. • Physical laws are applied in the virtual environment just as in the real world (physics-based simulations) . • Through digital twins in the metaverse and blockchain-supported logistics, transparency and visibility among stakeholders are enhanced, facilitating processes such as product traceability, smart contracts, and payments. • Manufacturers should collect data from processes, aggregate it, and use interoperability protocols to connect it across the supply chain. • It will have its own virtual economy enabled by digital currencies or NFTs.	• Prolonged use of the metaverse may lead to mental health issues similar to those caused by social media and gaming addiction, and can blur the line between the real and virtual worlds. • Internet speed is still very low • VR headsets need to be more ergonomic and lightweight . • As more data is collected in the metaverse, concerns regarding privacy, security, and identity management become significant challenges—exacerbated by the decentralized nature of the environment . • The advanced VR equipment required for the best metaverse experience is not yet widely available or affordable. The high cost of necessary devices limits widespread adoption. • This process requires a significant amount of energy.

Table 2 provides a comprehensive overview of both the opportunities and risks within the metaverse ecosystem. The findings indicate that, alongside innovations such as realistic interactions in virtual environments, digital twin applications, and NFT-based economies, limitations such as high costs, ergonomic concerns, and the potential for dependency must also be considered. To examine the advantages and disadvantages of the metaverse and to analyze its architectural aspects, several tables have been prepared. The following tables present these elements in a comprehensive and categorized manner.

2.1. Advantages and Disadvantages of Metaverse in terms of Architecture

Table 3 summarizes the advantages and disadvantages of architectural applications within metaverse environments, highlighting key aspects related to the design, use, and experience of virtual spaces. It also addresses the opportunities and limitations encountered across a broad spectrum—from student projects to professional applications—offering a comprehensive evaluation that can inform future architectural design processes.

Table 3. Advantages and Disadvantages of Metaverse in Architecture

Advantages	Disadvantages
• Since students are not required to physically visit construction sites, they avoid the risks associated with such visits, including safety hazards.	• Students reported difficulties in understanding scale, materiality, and the real-world experience of construction sites.
• The ability to navigate through different stages of the construction process in a virtual environment enhances students' understanding .	• Students reported experiencing dizziness and discomfort after prolonged use of smartphone headsets.
• Technologies such as Augmented Reality (AR) provide rich and immersive educational experiences that help students comprehend complex architectural concepts in an interactive and dynamic manner.	• Virtual environments, including metaverse platforms, often lack haptic feedback, making it difficult for students to fully understand material properties and the real scale of building elements.
• They offer continuous access to learning environments and enable students to revisit various stages of construction projects without the need for travel.	• Public and professional awareness of the topic remains limited; seminars and educational outreach are needed to address this gap.
• By integrating AR, VR, and digital interaction, metaverse environments cater to diverse student learning preferences.	• There is still limited understanding of this subject among individuals, and acquiring proficiency in it requires familiarity with a wide range of platforms.
• For architects and urban planners, the metaverse represents a new trend and opportunity for 3D visualization, 3D design, and their further development.	

This table reveals that while the metaverse architecture offers innovative design and educational opportunities in virtual environments, it creates various difficulties in users' interaction with the real world. The findings show that, despite the enrichment of the spatial experience, more research is needed on issues such as technological infrastructure, ergonomics and sustainability. In this way, the architectural dimension of future metaverse applications can become more functional and user-friendly.

3. Examination of Metaverse Applications in Architecture

In recent years, the number of architectural applications designed on metaverse platforms has been increasing. World-famous architectural offices are creating different designs on metaverse platforms. The most effective of these designs are Liberland city, José Cuervo Metadistillery and Metaserai. In this study, these designs were detail analysed. Liberland city that the digital city project was designed by Zaha Hadid Architects,. This design aims to create autonomous living spaces in the metaverse environment and allow users to experience digital interactions within sustainable urban structures. The Liberland Metaverse, where residents can buy vacant plots centered around a curated urban core, and access them as avatars. The community features hyper-realistic districts that encourage urban self-governance and zones where the absence of urban planning "allows for a spontaneous order via a free-wheeling discovery process". The project also comes as a response to the world's transformative and emerging notion to end stagnation and push for universal prosperity. The metaverse's open and transparent decentralized autonomous organization will have much greater demand and appeal over centralized corporate ventures, further accelerating this urban transformation. In Fig. 6., visuals of Liberland city are given.

Fig. 6. Liberland Metaverse City

Rojkind Arquitectos has ventured into the metaverse with the José Cuervo Metadistillery, a virtual experience center designed to foster social interaction and brand engagement. Inspired by the roots of the agave plant, the structure symbolizes connectivity and cultural heritage. Located within the Decentraland platform, the Metadistillery offers immersive activities such as a barrel maze, a floating volleyball pool, and a luminous agave garden, all culminating in a virtual bar to enhance communal experiences. This project exemplifies the potential of digital architecture to create inclusive, interactive spaces that transcend physical limitations. To create the Metadistillery, Rojkind Arquitectos collaborated with a group of experts and designers specializing in digital experiences: the agency Ache, specialized in creative development; the expert study in the Metaverse, Tangible; the largest video game district, Decentraland, the developers of the experience, Vegas City, Mekanism as a marketing agency; and the UK based dining experience experts, Bompass & Parr, tasked with creating the aesthetic and consumer experience. Within the infinitely diverse paths of "unique experiences," the digital world has permeated the imagination of millions of young people and created common environments with intuitive languages of interaction that pose digital challenges, where any subject can acquire an alternate identity through avatars in a new social context. In Fig. 7., visuals of José Cuervo Metadistillery are given.

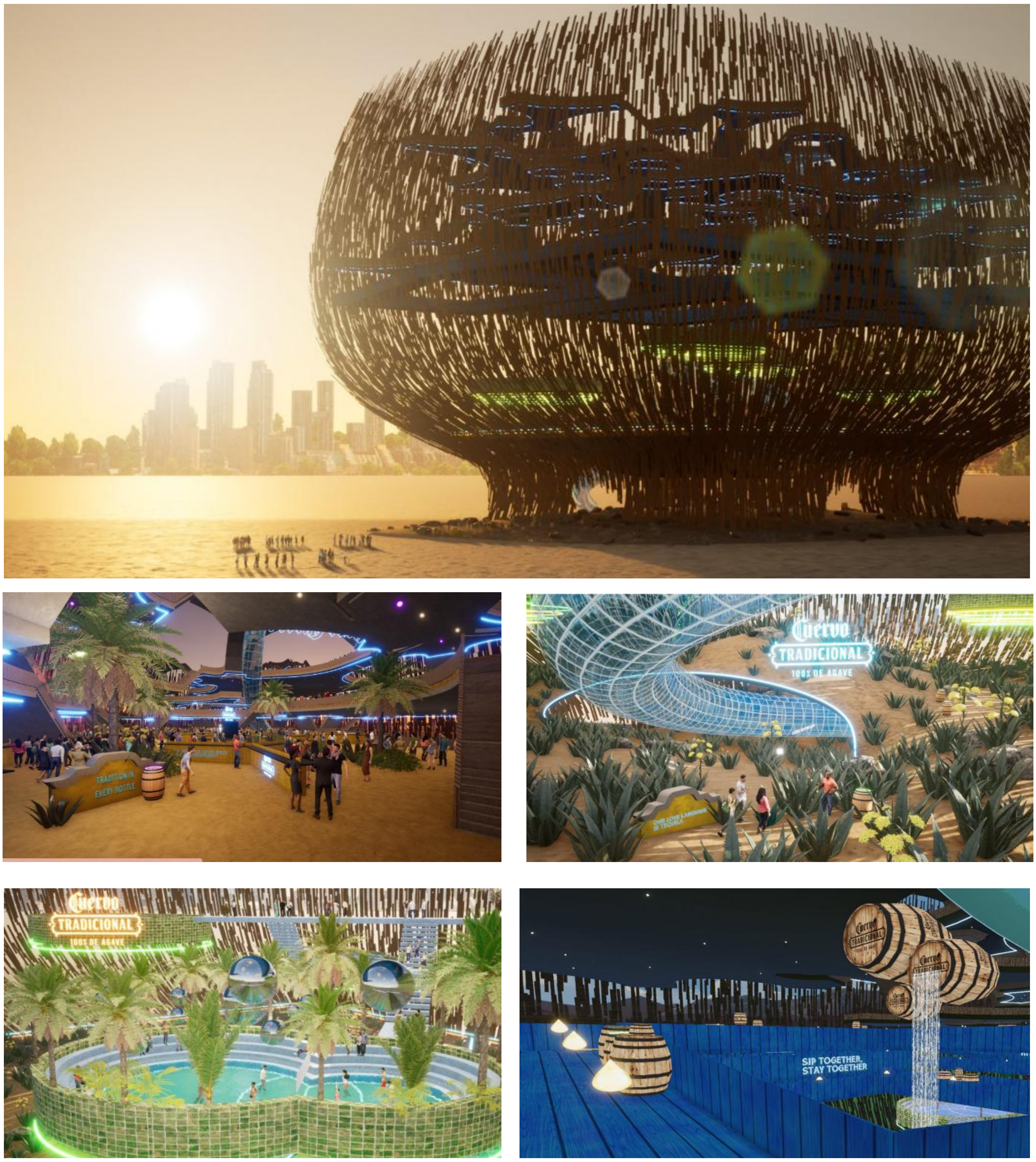

Fig. 7. José Cuervo Metadistillery

The metaverse platform pax.world has collaborated with renowned architecture firms Grimshaw, HWKN, Farshid Moussavi, and WHY to create "Metaserai," a series of virtual social hubs inspired by the Silk Road's caravanserais. These hubs are designed to host cultural, social, and educational events such as concerts, theater performances, digital art exhibitions, markets, lectures, and festivals. Each architectural firm offers its unique interpretation of the Metaserai concept, aiming to foster community interaction and cultural exchange within the metaverse. The project envisions a decentralized virtual society governed by a Decentralized Autonomous Organization (DAO), with Metaserai hubs serving as communal centers amidst privately owned virtual lands. The structure takes its cue from the architectural features of the caravanserai, a simple structure surrounding a central courtyard and watering point. The cuboid shape appears to levitate in its location. As it has no physical connections to the ground, visitors can enter through spherical follies or gates. The interactions between users will trigger a flow of data which will, in turn, influence the bespoke spaces, all generated from a kit-of-parts. This constantly shape-shifting architecture aims to reflect human interaction at a scale, speed, and scale impossible in a physical environment. In Fig. 8, visuals of Metaserai are given.

Fig. 8. "Metaserai," a series of virtual social hubs

4. Conclusions

Metaverse architecture offers innovative opportunities for design and education in virtual environments, it also presents various challenges in terms of users' interaction with the real world. The findings indicate that although spatial experiences are enriched, further research is needed in areas such as technological infrastructure, ergonomics, and sustainability. Addressing these aspects may lead to more functional and user-friendly architectural applications of the metaverse in the future.

Based on the previously discussed advantages and disadvantages, it is clear that the metaverse has existed in our world for several years, yet remains in continuous development. Like today's virtual platforms, the metaverse continues to evolve in response to user demands, offering increasing convenience in daily life. As a result, it holds the potential to further facilitate interactions and provide more immersive experiences.

However, like earlier technological advancements, the metaverse presents both opportunities and challenges. While it enhances flexibility and accessibility in learning, it is also limited by sensory constraints and technical issues—especially those critical to the accurate understanding of material perception and architectural scale. Addressing these challenges is essential to fully realize the potential of the metaverse in design and architecture.

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Fire risk assessment of atrium-planned shopping centers: The case of Ceylan Karavil Park Shopping Mall

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Abstract. Shopping centers are multifunctional public buildings designed to address a wide range of ergonomic needs, serving as spaces where various requirements of daily life are met and different user profiles converge. In the 21st century, shopping centers can be characterized as sheltered spaces with stabilized comfort conditions, designed to efficiently meet diverse needs within a short time frame while offering resilience to climatic conditions. In this context, given that users spend a significant portion of their time in these spaces, it is crucial to prioritize the design of transitional elements that connect indoor and outdoor spaces during the planning stages of such projects.The layout types aimed at increasing user potential must address fundamental requirements such as natural lighting, ventilation, and illumination. Among these design strategies, the atrium layout has emerged as a frequently preferred approach in shopping centers, particularly for its role in enhancing energy efficiency. However, ensuring fire safety in shopping centers with high human density is a critical concern. Within this framework, the study employs a case study method to evaluate the fire risk associated with atrium-planned shopping centers, focusing on Ceylan Karavil Park Shopping Mall located in Diyarbakır. The evaluation was conducted in accordance with the national fire precaution regulation**,** ensuring regulatory compliance in the assessment of fire safety components.The methodology incorporates on-site observations and regulatory compliance assessments to analyze fire escape routes, staircases, and both active and passive fire safety measures. The study concludes by proposing various recommendations to enhance fire safety in atrium-planned structures and emphasizes the need for broader research to support the safety performance of such buildings.

Keywords: Shopping Mall; Life Safety; Emergency; Fire; Diyarbakır; Emergency Action Plan (EAP)

1. Introduction

Shopping malls are not merely venues for fulfilling individuals' economic shopping needs but also multifunctional spaces for entertainment and social interaction. Shopping malls have become integral components of a widespread cultural phenomenon across all segments of society, regardless of age, economic status, or social class. Based on this phenomenon, stakeholders in the construction sector have been developing shopping mall projects to meet market demands. However, building designs must be prepared — starting from the early design stages and continuing through the operational period — within the framework of criteria such as fulfilling functional requirements, reliability, and usability (Marantika et al., 2020). In this context, shopping mall structures should not be designed solely on functionality or accessibility; the fact that these structures present a high fire risk must also be considered. In other words, ensuring fire safety in buildings with high occupant density constitutes an essential design strategy. Proper management of fire safety not only reduces the risk of fire and ensures the rapid and safe control of flames during a fire incident (Rubaratuka, 2013; Ahmad Sabri et al., 2023). The high fire loads characteristic of shopping malls necessitate the development of specific fire safety regulations. However, since fire safety measures and awareness are often not effectively communicated to the users of these spaces, the occurrence of related issues becomes inevitable (Othuman Mydin, 2013; Abdul Rahim et al., 2014).

Shopping mall structures are also considered gathering spaces that accommodate commercial, entertainment, and food and beverage functions. In particular, the upper floors, which house cinema halls and food courts, exhibit significantly high fire loads. Examining shopping mall unit plan typologies reveals that they often feature wide structures with atriums. While atriums contribute to energy-efficient solutions by providing natural lighting and illumination, they pose a significant fire risk, as fires can spread rapidly through these spaces. Therefore, atriums must be carefully evaluated as critical components of fire risk mitigation strategies.

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According to the literature, fire causes are often linked to gas leaks, negligence, and short circuits (Hafiz Mohd Noor and Hussien, 2020). In this context, the restaurants, cafes, and fast-food chains operating within shopping malls — which utilize large-scale gas-operated kitchen equipment — present substantial fire risks due to potential gas leaks or insufficient maintenance of exhaust systems. Another significant fire hazard in shopping malls is the extensive network of electrical systems, including lighting fixtures and escalators. Short circuits within these systems can be significant sources of fire risk (McGrath, 2020; Uluç et al., 2022). Furthermore, human errors and a general lack of fire awareness among users contribute to fire risks in shopping mall structures. Thus, developing and implementing effective fire prevention systems are imperative for these highly vulnerable building types.

Fire protection systems are generally categorized into active and passive measures. Active fire protection systems respond to and suppress fires manually or automatically once a fire is detected. In contrast, passive fire protection systems aim to limit fire spread through architectural design features such as material selection, compartmentalization, and insulation, offering protection without requiring active intervention (Drysdale, 2011). An integrated approach combining active and passive fire protection systems is essential to ensure fire safety in shopping mall structures. Creating fire compartments can help confine fires to limited areas, particularly in buildings with high fire loads. In other words, using fire-resistant building materials and establishing fire-rated cells are key passive strategies. Another important passive fire protection measure involves the creation of refuge areas, especially necessary in shopping malls where the evacuation of large crowds can be challenging. Refuge areas are temporarily safe zones isolated from smoke and flames (Tabassum et al., 2014; Yunus, 2021). Among the active fire protection systems employed in shopping malls are fire alarm systems, fire suppression systems, sprinkler systems, and smoke control systems (Della-Giustina, 2014; Kodur et al., 2019). Critical components include emergency lighting, illuminated exit signage, and unobstructed evacuation routes (Marantika et al., 2020). Additionally, provisions for fire brigade access, such as designated parking areas for fire engines, must be incorporated into the design to facilitate emergency response operations (Kikwasi, 2015; Taylor et al., 2019).

In conventional large-scale urban fire analyses, shopping malls are often treated as anonymous structures within standard datasets, with individual spatial differences being overlooked. However, each shopping mall exhibits unique characteristics in terms of atrium design, spatial organization, and user density, necessitating that the fire safety performance of each structure be assessed within its own specific context. Particularly in buildings with atrium plans, the dynamics of fire spread differ significantly, rendering evaluations based on general assumptions inadequate. Therefore, site-specific, field-based analyses are required. By considering real usage conditions, user habits, and spatial changes that occur over time, the fire safety performance can be presented in a more realistic manner. This study was conducted to identify deficiencies in current practice and to provide scientific data support for the development of safety-oriented design and operational strategies in public buildings with high human circulation, such as atrium-planned shopping malls. In particular, following the devastating earthquakes that struck southeastern Türkiye on February 6, 2023, shopping malls have come to be regarded not only as commercial facilities but also as designated emergency gathering areas. This shift in perception has significantly increased the importance of ensuring that such buildings are safeguarded not only against earthquakes but also against other potential disasters, such as fires. In this regard, considering the high fire risks associated with atrium-planned shopping malls, a case study was conducted on Ceylan Karavil Park Shopping Mall — the largest shopping mall in Diyarbakır, located in the Southeastern Anatolia Region of Türkiye — to propose preventive strategies and recommendations for fire safety both before and during fire incidents. Through on-site observations, photographic documentation, and spatial analyses, fire escape routes, emergency staircases, and the active and passive fire protection systems utilized in the structure were identified, and recommendations for enhancing fire safety in atrium-planned shopping malls were developed.

2. Materials and methods

Within the scope of this study, the fire safety of shopping mall structures, categorized among atrium-planned commercial buildings, was investigated using the case study method, one of the qualitative research approaches. Ceylan Karavil Park Shopping Mall, one of the largest shopping centers in Diyarbakır, Southeastern Anatolia Region of Türkiye, was selected as the study area. Both spatial characteristics and fire safety equipment were examined through on-site observations following active and passive fire protection methods. Additionally, archival research was conducted within the records of the Diyarbakır Metropolitan Municipality, and relevant architectural and engineering documents of the building were analyzed.

The study's methodology includes comprehensive on-site investigations of fire doors, staircases, escape routes, and fire safety systems, in accordance with the provisions of the national fire regulation (Regulation on the Protection of Buildings from Fire, 2009). Fig. 1 presents the overall framework of the study's methodology.

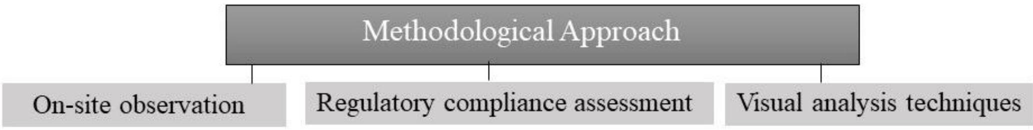


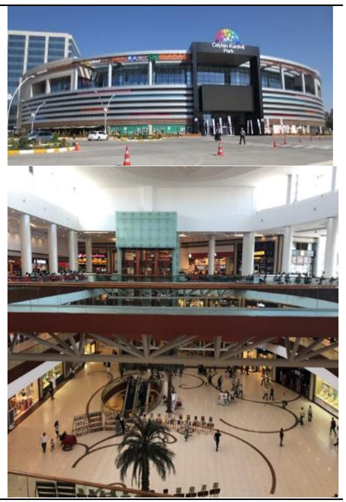
Fig. 1.Methodology of study

3. Results and discussion

The construction of Ceylan Karavil Shopping Mall, located in the Kayapınar district of Diyarbakır, commenced in 2008 and the mall was opened to the public in 2014. The project, designed by A Tasarım Architecture Office founded by Ali Osman Öztürk, stands among the significant commercial spaces in the Southeastern Anatolia Region of Türkiye.

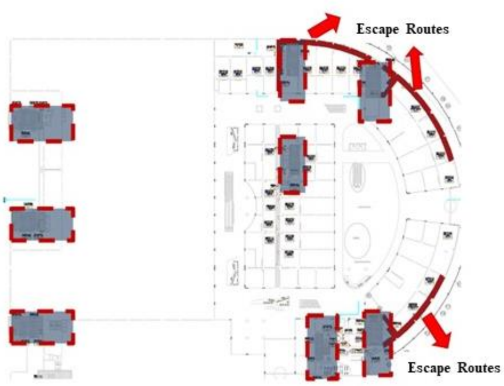
Table 1. General Information and Main Entrance View of Ceylan Karavil Shopping Mall (A Tasarım Mimarlık, 2025)

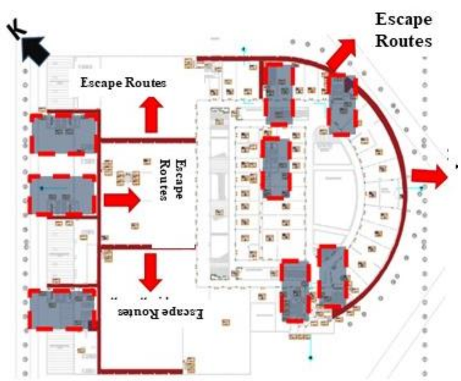
Project Type:	Shopping Mall
Project Location:	Diyarbakır/Turkey
Project Category:	Commercial
Architectural Design:	A Tasarım Architecture Office
Project Architect:	Ali Osman Öztürk
Construction Completion Year:	2014
Total Construction Area:	160,000 m²



The structure, located along Şanlıurfa Boulevard, which is recognized as the main arterial road of Diyarbakır, is also situated at a nodal point connecting the city's rapidly developing residential and commercial areas. The building features an atrium plan typology, and atriums and terraces have been designed to ensure the fluidity between interior and exterior spaces (A Tasarım, 2025).

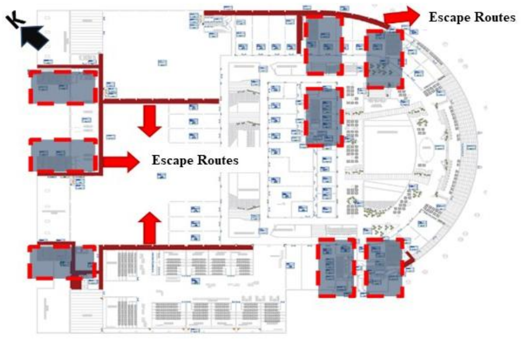
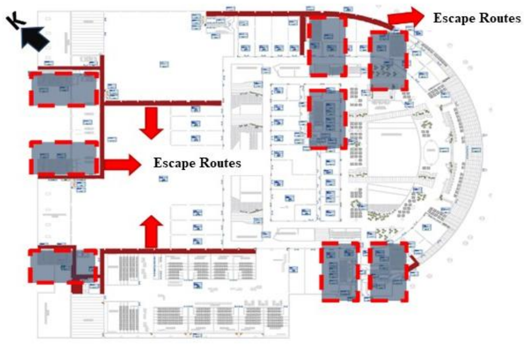
Table 2. Locations of Escape Routes and Staircases (Compiled by the author from the Diyarbakır Yenişehir Municipality Archives)





Ground floor plan	First floor plan

Table 2 continued

	
Second floor plan	Third floor plan

The building contains a total of 13 fire escape staircases. According to the Fire Protection Regulation (Resmi Gazete, 2009), the riser height of fire escape stairs must not exceed 18 cm, and the tread width must not be less than 20 cm. In the examined structure, it was determined that the tread width is 23 cm and the riser height is 17 cm. Therefore, it was confirmed that the staircase dimensions comply with the fire safety regulation requirements. The building also features three designated fire escape corridors. The escape route located on the southeastern façade curves to serve multiple fire staircases. Additionally, on the northwestern side of the building, vertical escape routes are connected to fire staircases through horizontal escape corridors. On the third floor plan, three independent fire escape corridors were identified. For fire staircases that are not directly connected to an escape corridor, fire lobbies equipped with a pressurization system have been designed to prevent the spread of fire into the staircases. The fourth floor serves as the roof level, where vertical shafts (ducts) are extended upward. In compliance with fire safety regulations, escape routes must be free from any obstructions. However, field observations revealed that in some floors, objects such as boxes and shopping carts were present on the escape paths, posing significant risks to the safe evacuation of occupants during a fire incident.

According to the provisions of the regulation, the minimum clear width of fire escape doors must be at least 80 cm, and the minimum door height must be at least 200 cm (Resmî Gazete, 2009). To ensure the safe evacuation of sufficient occupants during a fire emergency, the door dimensions along escape routes must be designed following these requirements. Furthermore, there must be no thresholds or obstacles in the areas where fire exit doors are located, allowing level and unobstructed passage.

In the evaluated structure, the fire exit doors' width was 100 cm, and no thresholds were observed. Exit doors leading into internal escape corridors or passageways must have fire resistance equivalent to main escape doors and be equipped with self-closing mechanisms. It was determined that all fire exit doors in the building had panic bars.

Fig. 2. Emergency exit doors of fire escape routes

In complex structures such as shopping malls, where multiple exits are available, it is essential to guide occupants correctly toward the appropriate exit doors during a fire emergency. In case of an emergency, the locations of exits to be used for evacuation must be clearly indicated within the building, and planned evacuation routes must be adequately displayed to occupants from every point inside the structure. Additionally, emergency exit signs must be installed at the height of 200 to 240 cm from the floor level (Resmî Gazete, 2009).

The emergency evacuation signs within the building are not positioned at a height between 200 and 240 cm as required. Instead, these signs were found to be installed at the ceiling height of each floor. However, when the building was evaluated as a whole, it was determined that the emergency wayfinding signs, lighting, and markings along the escape routes were implemented in accordance with the relevant regulations. Active fire safety measures consist of all precautions taken to detect a fire at its earliest stage and to automatically or manually intervene in order to limit potential damage and to facilitate rescue operations. These measures are categorized into two main groups: fire detection and alarm systems, and fire prevention and suppression systems (Resmî Gazete, 2009).

Fig. 3. Emergency evacuation signs

Fire detection and alarm systems must be activated through manual intervention, automatic detection, or signals received from a suppression system. Manual activation is provided via fire alarm buttons installed along fire escape routes. According to the relevant regulation, the accessibility distance to a fire alarm button from any point on a floor must not exceed 60 meters; in areas where disabled and elderly individuals are present, this distance must be reduced. Furthermore, all fire alarm buttons must be clearly visible, easily accessible, and mounted at a height between 110 and 130 cm from the floor (Resmî Gazete, 2009). Upon examination of the shopping mall structure, it was observed that some fire alarm buttons were obstructed by barriers. Although the accessibility distances were designed appropriately to accommodate individuals with disabilities and elderly users, the visibility of the alarm buttons was compromised by lighting fixtures or advertising panels belonging to individual stores.

Fig. 4. Sprinkler Systems

According to the regulation, fire alarms must be accessible, and no obstacles should be placed in front of them that would impair their visibility. However, in the examined building, it was observed that some fire alarms were obstructed by advertising panels (Fig. 5). Fire pumps are pumps that supply pressurized water to water-based fire suppression systems and are defined by their rated flow and rated pressure values (Resmî Gazete, 2009). In the event of a fire, water reservoirs must be provided to meet the water demand of the sprinkler systems. It was confirmed that the current building is equipped with water reservoirs.

Fig. 5. Fire alarm systems

According to the Fire Regulation, fire hose cabinets must be installed in healthcare, hotel, and commercial buildings with a construction area exceeding 3,000 m². In addition, electrical cabinets must remain closed, and the cables must be maintained without wear in order to prevent potential leakages. Upon examination of the building, it was determined that the fire hose cabinets and electrical cabinets were designed in accordance with the regulatory requirements.

Fig. 6. Fire Pumps and booster systems

4. Conclusions

Fire constitutes a significant risk factor, particularly in large-scale structures. In this context, it is essential to correctly implement fire safety measures in multifunctional building types, such as shopping malls, where occupant density is considerably high, to minimize potential losses. Accordingly, Ceylan Karavil Shopping Mall, recognized as one of the significant commercial structures in the Southeastern Anatolia Region, was selected as the case study area, and the fire safety aspects of the building were examined using qualitative research methods. The passive and active fire protection measures implemented in the structure were evaluated and compared in accordance with the Fire Regulations. It was determined that the fire hydrants, hoses, and reels intended for use during fire emergencies were designed in compliance with the regulatory standards.

It was determined that the fire suppression systems, sprinkler systems, fire hose cabinets, and water reservoirs were constructed following the relevant standards. However, during an emergency, the approach distance required for fire trucks was obstructed by various barriers, preventing efficient access. Moreover, although emergency signage and lighting are present within the building, their installation heights and placements do not comply with the prescribed standards.

Regarding passive fire protection measures, the examination revealed that the widths and dimensions of the escape corridors were initially designed in compliance with the regulations; however, due to improper usage, escape paths have been partially obstructed by waste materials and temporary barriers. It was also confirmed that the panic bar-equipped doors along fire escape routes comply with the required height and width standards and that the emergency lighting systems along escape and exit routes are actively functioning.

Additionally, the inspection of electrical cabinets and wiring revealed worn and aged cables throughout the building. Table 3 summarizes the existing active and passive fire protection measures, along with the identified deficiencies.

Table 3. General evaluation of active and passive fire protection measures in Ceylan Karavil shopping mall

Active Fire Protection Measures		Passive Fire Protection Measures	
Fire hydrants / Hose reels	√	Obstacles such as waste and trash present in escape routes	✖
Manual fire alarm call points partially obstructed by barriers		Directional signage and lighting along escape routes installed	√
Fire suppression systems	√	Stair risers designed according to regulations; however, non-slip bands were not applied	√
Sprinkler systems	√	Panic bars installed on fire escape doors	√
Fire boosters (hydrophores)	√	Fire escape corridor widths designed in accordance with regulations	√
Fire pumps	√	Presence of exposed installations in escape corridors that may cause electrical leakage	✖
Water reservoirs for fire systems	√	Lighting systems along escape and emergency exit routes functioning actively	√
Fire hose cabinets and extinguishers	√	Exit signage is functional and operational	√
Fire truck access to the building is difficult due to various obstructions	✖	Smoke doors designed with proper sealing as per regulations	√
		Directional signage and lighting are available, but installed at ceiling height rather than 200–240 cm	✖

Based on the findings, it was concluded that the building was initially designed in compliance with the Fire Regulations; however, improper use and lack of user awareness over time have significantly increased the fire risk. Consequently, the following recommendations are proposed for improving fire safety in shopping mall projects:

- Escape routes within the building must always be kept clear, and elements that may obstruct evacuation, such as waste, stands, and temporary exhibition units, should be regularly monitored and removed.
- Fire-resistant curtain systems or automatic smoke curtains should be installed on floors opening into atrium spaces to prevent the spread of smoke and flames during a fire incident.
- A continuous fire access road and sufficient maneuvering space should be provided around atrium-type shopping malls to ensure that fire trucks can rapidly and unobstructedly access the building. These areas must be kept free of obstructions at all times.

- To increase fire safety awareness, regular fire drills and emergency response training should be organized for shopping mall employees and visitors.
- Directional and emergency exit signs must be placed at locations that are easily visible both horizontally and vertically, considering the building's spatial volumes, and must comply with regulatory standards.
- A regular maintenance and repair program must be established to address the deterioration and aging of the building's electrical wiring.
- Implementation of Natural Smoke Ventilation Shafts: Automatic operable roof windows or natural ventilation shafts should be integrated into the upper sections of atrium spaces to ensure the vertical discharge of smoke during fire incidents.
- Installation of Fire Curtains Around Atrium Openings: To prevent the horizontal spread of smoke and hot gases, automatic fire curtain systems should be installed around atrium openings to create compartmentalized zones.
- Use of High-Discharge or Water Mist Sprinkler Systems: In addition to standard sprinkler installations, high-throw or water mist sprinkler systems should be employed to ensure effective fire suppression in large-volume atrium spaces.
- Regular Fire Evacuation Simulations with Computer-Based Tools: Performance-based fire evacuation simulations should be conducted periodically using specialized software to assess and optimize evacuation strategies based on user density and building configuration.
- Enhancement of Emergency Public Address Systems: In wide and tall atrium areas, emergency public address systems should be designed to deliver clear and audible evacuation instructions throughout the entire space, ensuring effective user guidance during emergencies.

Fire safety in shopping malls must not only be considered during the design stage but also actively maintained throughout the operational life of the building. Continuous monitoring, user awareness, and regular inspections are crucial to sustaining fire safety measures. The findings of this study highlight that fire safety requires ongoing user discipline and cannot be ensured solely through structural solutions. Awareness-raising initiatives and training programs aimed at employees and visitors are vital to ensuring the continuity of fire safety. Through such efforts, it is possible to eliminate human-related risks that hinder rapid intervention during a fire event, thereby minimizing potential loss of life and property.

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Structural system interventions in adaptive reuse of industrial buildings: The case of Ayvalik Rahmi Koc Museum

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Abstract. Industrial buildings reflect the changes and developments of the Industrial Revolution in both technology and social life. Furthermore, these buildings have gained a place in the social and economic memories of cities. However, such buildings have lost their functions over time and left idle within the developing urban fabric, facing the danger of extinction. The concept of 'Industrial Heritage' has emerged due to this. With this well-known worldwide concept, the principles of adaptive reuse, intervention methods, and function selection have also gained importance. In addition, the structural systems, architectural features, and values of these buildings have begun to be considered.

In this study, an industrial building located in Ayvalık, Balıkesir, which has an essential place among the industrial heritage examples in the Aegean Region, is examined. Although the structure preserved its original plan scheme, it has deteriorated significantly over time, and therefore, comprehensive repair and improvement were needed. In this research, the structural system requirements and interventions made to the structural system of this masonry structure which was previously used as an olive oil factory -later reused as a museum, were examined within the framework of national and international standards. In this context, the structural system types used in both cases of the structure were determined and categorized, and a structural system conformity assessment was evaluated based on the Turkish Building Earthquake Code (TBDY 2019), European Standards (Eurocode), and American Standards (ASCE/SEI).

This study aims to document the adaptive reuse applications of industrial buildings in Turkey, minimize errors in similar applications, and encourage the preservation of such structures.

Keywords: Industrial heritage; Structural system; Adaptive reuse; Conservation; Structural codes

1. Introduction

The Industrial Revolution began in England in the 18th century and quickly became one of the most crucial turning points affecting the world. With this revolution, production methods and production processes radically changed, as the production methods previously carried out in small-scale workshops using traditional techniques gave way to production in large spaces where mechanization was available. This transformation brought about the updating of the architectural and structural system designs of the buildings with the change of spatial requirements such as the need for wide open spaces. In the 20th century, while production methods continued to develop, the industrial zones that were previously located outside of the city center remained within the urban fabric. With the loss of their functions, the necessity and need for the preservation and adaptive reuse of industrial buildings emerged. While implementing these phenomena in industrial buildings, the structural system features, current status, and structural requirements of the buildings should also be taken into consideration. Since the industrial heritage buildings had not been designed according to modern-day engineering principles and regulations or had several damages because of wear and tear, lack of maintenance, problematic interventions on the structural system, exposure to atmospheric conditions, and earthquakes after long years of use, structural interventions may be required in the adaptive reuse processes of these buildings. Industrial heritage buildings should also be evaluated in spatial and socio-cultural contexts, and it is of great importance that new functions are selected by the original character of the structures and that the interventions are reversible, sustainable, and by conservation principles. In this context, the main purpose of the study is to analyze the structural system conditions of industrial heritage buildings before and after reuse implementations and to make an evaluation within the framework of national and

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international standards (TBDY 2019, Eurocode 8, and ASCE/SEI 7-22) and general engineering principles in this process. In addition, the development of structural strategies for the sustainable transformation of existing structures and the promotion of cooperation between the disciplines of architecture, engineering, and conservation are also significant goals of the study.

2. Methodology

Firstly, in the structural documentation and information collection process, reports, photographs, historical building survey projects, restitution projects, and restoration projects of the case study were obtained from the architectural design team. The current condition and before the adaptive reuse process of the building, the structural system components also were cataloged in this step. Secondly, in the standard analysis phase, three different regulations from different regions (TBDY2019, Eurocode 8, and ASCE/SEI 7-22) and general engineering principles were examined, and an analysis table was prepared for the structural system requirements. The requirements of each standard and, in matters not specified by the standards, general engineering principles have been systematically identified. This table has also made it possible to analyze and compare the approaches of different regulations and general principles to structural requirements. In these analysis tables, basic structural design principles and structural system requirements for each type of structural system have been evaluated. Each parameter has been separately evaluated for each regulation and general engineering principle, and the results have been marked in the table. During the visualization phase, the irregularities were defined using a specific coding system that comes from the analysis table marked on the project drawings. The structural system, plan layout, and irregularities have been visualized using different line types and colors. In the results evaluation phase, the pre- and post-conditions of the building were evaluated in terms of the requirements of different regulations, and the similarities and differences between the standards were specified. This evaluation was made only in terms of compliance criteria, without any performance analysis. This four-step methodology allows for the systematic analysis of structural systems in adaptive reuse industrial buildings and the comparative evaluation of different regulations and standards.

3. Results and Findings

The olive oil factory, located in the Sakarya Neighborhood of Ayvalık District, Balıkesir province, between Government Street and the sea, was built by Anastasyos Yorgolos of Greek origin in 1910 and was transferred to the Emvali Metruka Administration during the exchange period. The ownership of the factory passed to Kahraman Bahadır, the Güldenoğul Family, and the Ertem Family, respectively (Yıldız, 2017). In the first land registry records, there was the phrase “masonry factory with oil house, soap house, machine and boiler room, and house” (EMR Architecture, 2024). In addition, it was determined that there was a building next to the factory building, which was in the use of the family, but this building was demolished by the Ertem Family in 1954 (Yıldız, 2017). General information about the structure is provided in Table 1 while, the condition of the building before adaptive reuse is shown in Fig. 1, and after reuse in Fig. 2.

Table 1. Building Data Sheet

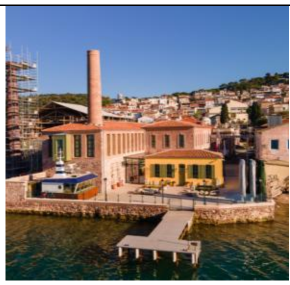
General Data	Before Reuse	After Reuse
Photograph	 Fig. 1 Condition of the building. (EMR Architecture, 2024)	 Fig. 2. Condition of the building. (EMR Architecture, 2024)
Construction year	19th Century	Jan.,2024
Team/Institution	Anastasyos Yorgolos	EMR Architecture
Public use	Public use not available	Public use available
Function	Olive oil factory	Museum
Addition	Inappropriate addition existed	Inappropriate addition does not exist

Table 1. Continued.

Structural System Characteristics		Before Reuse	After Reuse
General Features	Number of stories	2 Floors, Ground + 1st Floor	Partial Basement + Ground + 1st Floor
	Plan geometry	L-shaped plan: 16.72m x 38.75m	L-shaped plan: 16.72 m x 38.81 m
	Composite element	Does not exist	It is present due to the reinforcement system
System Features	Building Type	Masonry frame system	Composite masonry frame system
	Wall type	Part stone, part brick wall	Part stone, part brick wall
	Attic	Does not exist	Does not exist
	Basement	Does not exist	Partial basement added
Structural Elements		Technical features/Material	Technical features/Material
	Walls	Ground floor 45-50 cm stone, 1st floor 25 cm brick	Ground floor 45-50 cm stone, 1st floor 50 cm brick
	Columns	22 cm diameter, 19 x 27 cm rectangular section timber columns	HEB240 steel profile
	Beams	22 cm x 22 cm square section and 22 cm diameter circular section timber beams	NPI120 steel profile, 22 x 22 cm square section and 22 cm diameter circular section timber beam, 21 x 27 cm section wood-steel composite beam
	Floors	Timber beam floor	Composite floor / Timber-steel
	Roofs	Timber pitched roof	Timber pitched roof

3.1. Analysis of the Structural System Before and After Adaptive Reuse

3.1.1. Assessing the Condition and Structural System of the Building Before Adaptive Reuse

The structural system of the original building, which consists of two floors, the ground floor and the first floor, is a masonry carcass construction system supported by a timber frame system in order to increase the durability of traditional masonry buildings. The building in consideration is comprised of two rectangular sections, with common walls, and has an L-plan geometry. There is also a single-storey reinforced concrete structure with a rectangular plan measuring 4.69 m x 19.72 m attached to the building. The masonry stone has been used for the ground floor's exterior walls, and the first floor also had masonry stone and brick on the exterior walls. The thickness of exterior walls varies from 40 to 50 cm at the ground floor and approximately 25 to 35 cm at the first floor. The common walls between two partitions on the ground and first floors of the building had shifted from their axis over time, and also reinforced concrete structural elements added later had caused the wall to deteriorate on the ground floor. In addition, while the building's integrity was mostly preserved on the ground floor, the first floor was greatly damaged due to the collapse of the roof elements and part of the wall in the long direction (EMR Architecture, 2024). It was determined that the masonry brick wall on the middle axis of the longest facade of the first floor, which is 38.75 m long, had collapsed, most of the window openings on this facade had been covered with bricks, and some of the windows had disappeared. The most deteriorated/changed facade that had suffered in the building was that facade because of these reasons. There were ten circular-section timber posts, two rectangular-section timber posts, and one stone column on the ground floor, and eight nearly rectangular timber posts on the first floor. The cross-sectional dimensions of the vertical load-bearing elements on both floors varied, and the elements were not placed in a regular way. The two main rectangular sections of the building were covered with two hipped roofs at different levels, which were mostly damaged or collapsed. In this context a conformity assessment chart for the basic principles is given in Table 2, and structural system is Table 3.

Table 2. Evaluation of Compliance with Structural Requirements Before Adaptive Reuse: A. Basic Principles

Code	Parameters	Compliance Check According to Structural Standards			
		1. TBDY19	2. EC8	3. ASCE/SEI 7-22	4. General Principles
1	Simplicity of the Structural System	**X** Simplicity is recommended.	**X** Simplicity is recommended.	**X** Simplicity is recommended.	**X** Simplicity is recommended.
2	Symmetry of the Structural System	**X** It is not symmetrical	**X** It is not symmetrical	**X** It is not symmetrical	**X** It is not symmetrical
3	Presence of floor discontinuity and slab openings	**X** Exists due to different floor levels.	**X** Exists due to different floor levels.	**X** Exists due to different floor levels.	**X** Exists due to different floor levels.

Table 2. Continued.

4	Presence of recesses and protrusions in the plan	X 15.5 m/38.72 m= 40% >20%	X Recess area/total area 128 m²/528,81 m²=24,21>5%	X 15.5m/38.72m>20	X High plan recess not advised (structure needs seismic joint)
5	Spread of elements in both directions	X Structural system is not balanced.	X Structural system is not balanced.	X Structural system is not balanced.	X Structural system is not balanced.
6	Orthogonality of structural system axes	X Structural system is not orthogonal.	X Structural system is not orthogonal.	X Structural system is not orthogonal.	X Structural system is not orthogonal..
7	Torsional irregularity	X Irregularity coefficient is between 1.2 and 2	X Two prevention methods proposed.	X Irregularity coefficient is greater than 1.4	X The rates are not optimal.
8	Discontinuity of vertical elements	X The system is not continuous.	X The system is not continuous.	X The system is not continuous.	X The rates are not optimal.
9	Strength irregularity between floors	X There is shear irregularity.	X There is shear irregularity.	X There is shear irregularity.	X There is shear irregularity.
10	Earthquake joint requirement	X Required (see A4.1)	X Required (see A4.2)	X Required (see A4.3)	X Required (see A4.4)
11	Expansion joint	— Not present.	— Not present.	— Not present.	— Not present.
12	Seating joint	— Not present.	— Not present.	— Not present.	— Not present.

Table 3. Evaluation of Compliance with Structural Requirements Before Adaptive Reuse: B. Structural System

Code	Parameters	Compliance Check According to Structural Standards			
	Masonry Building	1. TBDY19	2. EC8	3. ASCE/SEI 7-22	4. General Principles
1	Building height limit	✓ 9,25 m<10,5 m 8,70 m<10,5 m	— No limit is specified.	✓ 9.25m<10.70m 8.70m<10.70m	✓ It is appropriate.
2	Storey height	X Wall height/wall thickness= 7,1<9	X Wall height/wall thickness= 7,1<9	✓ Wall height/wall thickness 3.55 / 0.50 m<20; 3.79 / 0.50m<20	X 3.55 m>3 m; 3.79 m>3 m
3	Cantilever& span length	— Not present.	— Not present.	— Not present.	— Not present.
4	Existence of basement floor	— There is no partial or full basement.	— There is no partial or full basement.	— There is no partial or full basement.	— There is no partial or full basement.
5	Minimum wall thicknesses	X First Floor 25 cm<35 cm	X First Floor 25 cm <35 cm	✓ First floor 25cm>20.3	X First floor 25 cm<50 cm
6	Maximum unsupported length of walls	X 23,15 m>7,50 m	X 23,15 m>7,50 m (7,50=wall thickness x 30)	X Wall length/wall thickness 38,76 m/0,25 m>20	X Needs vertical ties or perpendicular wall support.
7	Total length limit of load-bearing walls	— No limit is specified in the standard.	— No limit is specified in the standard.	— No limit is specified in the standard.	X X direction 55.57/ 528.32 = 0.10<0.25 X Y direction 107.65/528.32=0.20< 0.25

Table 3. Continued.

8	Ratio of door/window opening lengths to wall length along the unsupported wall length	✓ Most favorable wall window/wall 1.7 m/8.32m= 0.25<0.40	✓ 1.7 m<8.32 m / 4=2.08m	– No criteria are specified in the standard.	✓ There is a wall in accordance with general principles.
		X Most unfavorable wall 16.37 m/23.15 m = 0.70>0.40	X 16.37 m>23.15 m/4	– No criteria are specified in the standard.	X Load-bearing walls should have low opening ratios
9	Distance between building corner and door/window opening	X Shortest wall: 0.92 m < 1.00 m (1st floor).	✓ Min. length > Wall height / 5 0.92 m > 0.64 m	X Min. length > 3 x wall thickness, 0.92 m < 1.50 m	X It is not suitable.
10	Wall length between door/window openings	X Shortest wall length 0.52 m<1.50 m (first floor)	✓ Total of opening heights/wall thickness 4,02 /10<30	X Min. length>6 x wall thickness, 0.52 m<3.00 m	X It is not suitable.
11	Perpendicular intersecting walls and openings	X Shortest wall length 0.64 m<1.00 m	– No criteria are specified in the standard.	X Min. length>3 x wall thickness, 0.64 m<1.50 m	X It is not suitable.
12	Length of solid wall between openings	✓ Longest wall opening 1.65 m<3.00 m	– No criteria are specified in the standard.	– No criteria are specified in the standard.	✓ Longest wall opening 1.65 m<3.00 m

It is seen that the condition of the building was quite problematic due to the fact that the loadbearing walls were not designed in a balanced way and the timber elements had an irregular and almost random placement. There is a presence of recesses and protrusions in the plan irregularity in all regulations and general design principles. This irregularity also corresponds to the creation of earthquake joints in empirical structural design principles. The fact that the two sections of the first floor of the structure have a height difference of approximately 30 cm from each other and the floors are not in the same plane/level also creates horizontal discontinuity. It is thought that the vertical elements/timber posts on which these floors were supported would be subjected to shear stress. The fact that the timber load-bearing elements were not orthogonal in the plan became largely compatible with all three standards. The load-bearing elements were not continuous between the floors and have different heights. Despite attempts to ensure proper load transfer from timber beams and roof trusses to masonry walls, irregular load transfer through these insufficient support elements caused damages to walls, slabs, and roofs. This discontinuity and the unbalanced placement of the loadbearing elements increased the tendency for torsional irregularity in the building. Thus, this design was negative according to all standards and general principles. There was no dilatation between the sections of different parts. This is also a reason for creating a seismic joint because two rectangular sections need to be separated by dilatation in order to move independently of each other under seismic loads and not affect each other negatively in the framework of modern regulations. Although the limit values regarding the arrangement of joints are clear in the context of empirical principles, these limit values are not clearly mentioned in modern regulations, but this separation is recommended in all three standards. According to the report, building height complies with TBDY2019 and ASCE-SEI 7/22 limits for both sections and general principles, despite no criteria in EC8. Ground floor height exceeds TBDY2019 and EC8 limits but remains within ASCE/SEI 7/22 values. The northeast facade's loadbearing wall, has thinned compared to other walls and decreased to 25 cm; it has a weak feature in terms of statics due to the lack of support elements for 38 m and having 33 window openings. In addition, the destruction that occurred in the middle axis of this wall is a result of the wall being weak in terms of statics. The largest unsupported length of the walls did not comply with all three standards and general principles. Although there is no limit specified in the standards regarding the total length limit of the load-bearing walls, according to general principles, the ratio of the load-bearing walls to the gross area of the structure in both directions is less than 0.25 on the ground floor, and this causes the loads to be unbalanced. When examining openings in load-bearing walls, the ratio of door/window opening lengths along the unsupported wall length to the wall length reduces the load bearing capacity; this ratio should not be less than 0.40 in TBDY2019 and 0.25 in EC8, while ACI 530-13 provides no specific ratio. The minimum length between openings is not suitable according to all standards and general principles. No criteria are specified in EC8 regarding the length between the wall and the opening that intersect each other perpendicularly. However, there were negative walls below the limit values given in TBDY2019 and ACI 530-13. The longest opening ratio in the plan is determined only in TBDY2019, the most negative wall, which is 165 cm long, is smaller than the limit criterion of 300 cm and remains within the limits. Irregularities identified through structural assessment are marked in Fig. 3 and Fig. 4.

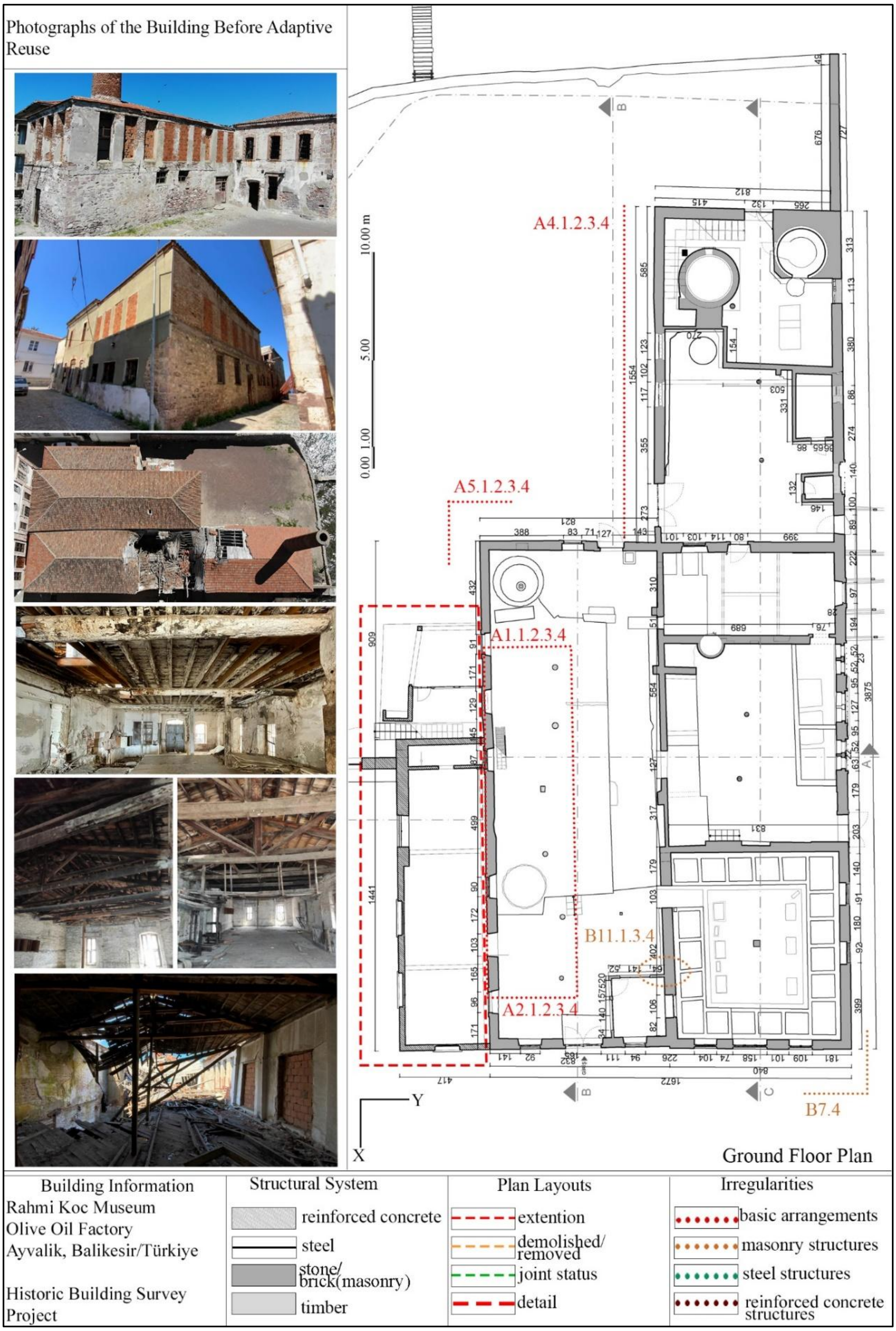


Fig. 3. Ground Floor Plan and Photographs (Modified by the author based on EMR Architecture, 2024.)

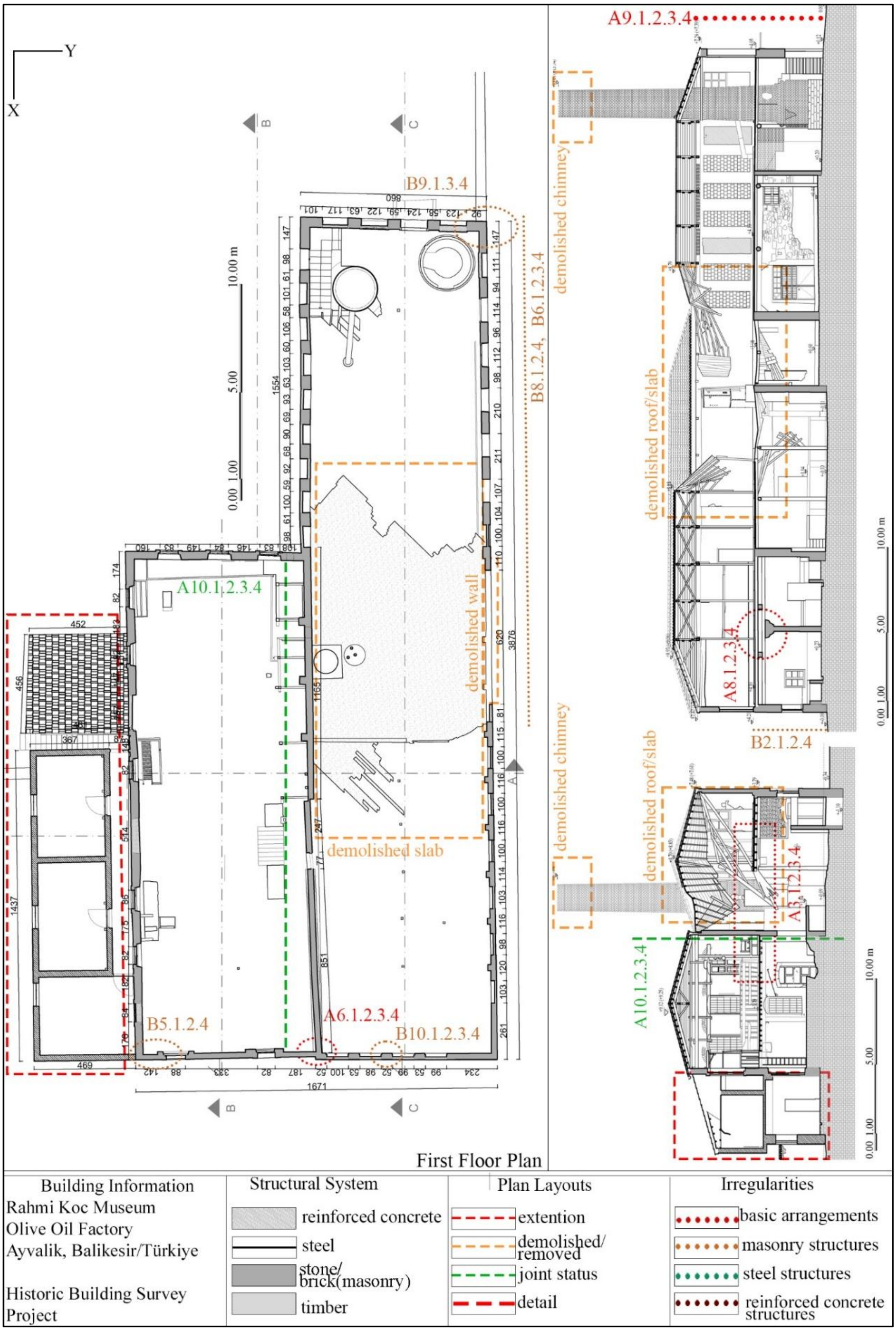


Fig. 4. First Floor Plan and Sections (Modified by the author based on EMR Architecture, 2024.)

3.1.2. Assessing the Condition and Structural System of the Building After Adaptive Reuse

The plan boundaries of the main factory building were preserved with the restoration applications, and the reinforced concrete building, which was added to the building later, was removed. In addition, the demolished building's location of the foundation walls was revealed with excavation works, and then the reconstruction of the building was carried out in the same area. A partial basement floor was built under the entire short section and a part of the long section to meet the museum's requirements, such as providing technical space and storage. When adding a basement floor, it was planned to preserve the original masonry wall up to the foundation level and to create an additional reinforced concrete wall around the basement floor (Emr Architecture Archive). The closed window openings were opened throughout the building; also, the damaged/lost doors and windows were remade based on the original ones. However, the door size was modified on some walls according to the museum's requirements. In addition, while the level differences of the ground floor's stone coated slab were corrected, the floor was also renewed. Applications such as completing the damaged wooden coverings and closing the gaps in the slabs that had occurred over time were implemented. Furthermore, the 30 cm level difference between the slabs was preserved while providing access between these two main parts on the first floor by a wooden ramp. Some restoration applications were implemented such as integration, renovation, and repair elements to the roof structure which was damaged and partially collapsed. Besides, these applications covers the preservation of the original timber beams and truss elements, and the reproduction of the structural elements with insufficient cross sections, which were determined to have been added later, in their original dimensions (Emr Architecture Archive). The reinforcement of the walls was done by applying injection to the stone and brick walls on the ground floor and by supporting the walls with sheet metal moldings added to the window openings in the short rectangular section in the plan on the first floor. However, since the opening dimensions in the long direction doubled and the wall thickness decreased to 25 cm, additional reinforcement methods had to be applied in this section. The demolished sections of the walls were completed with the original brick and bonding method. Furthermore, the areas that lost their quality were integrated with bricks after the decay process. In addition, some walls on the first floor were wrapped with fiberglass from the inside, and an additional brick layer was laid on the mesh in order to increase the thickness of the wall section. Also, the demolished chimney was integrated with the original height and bracelet detail in the approved restitution project. In this context a conformity assessment chart for the basic principles is given in Table 4, and structural system is Table 5.

Table 4. Evaluation of Compliance with Structural Requirements After Adaptive Reuse: A. Basic Principles

Code	Parameters	Compliance Check According to Structural Standards			
		1. TBDY19	2. EC8	3. ASCE/SEI 7-22	4. General Principles
1	Simplicity of the Structural System	**X** Simplicity is recommended.	**X** Simplicity is recommended.	**X** Simplicity is recommended.	**X** Simplicity is recommended.
2	Symmetry of the Structural System	**X** It is not symmetrical.	**X** It is not symmetrical.	**X** It is not symmetrical.	**X** It is not symmetrical.
3	Presence of floor discontinuity and slab openings	**X** Exists due to different floor levels.	**X** Exists due to different floor levels.	**X** Exists due to different floor levels.	**X** Exists due to different floor levels.
4	Presence of recesses and protrusions in the plan	**X** 15.5m/38.81m 39% >20%	**X** Recess area/total area 131 m²/530m²= 24,71>5%	**X** 15.5m/38.81m>20	**X** High plan recess not advised (structure needs seismic joint).
5	Spread of elements in both directions	✓ It is substancially balanced.	✓ It is substancially balanced.	✓ It is substancially balanced.	✓ It is substancially balanced.
6	Orthogonality of structural system axes	✓ Structural system is orthogonal.	✓ Structural system is orthogonal.	✓ Structural system is orthogonal.	✓ Structural system is orthogonal.
7	Torsional irregularity	**X** Irregularity coefficient is between 1.2 and 2	**X** Two prevention methods proposed	**X** Irregularity coefficient is greater than 1.4	**X** The rates are not optimal.
8	Discontinuity of vertical elements	✓ The system is not continuous.	✓ The system is not continuous.	✓ The system is not continuous.	✓ The system is not continuous.
9	Strength irregularity between floors	**X** There is shear irregularity.	**X** There is shear irregularity.	**X** There is shear irregularity.	**X** There is shear irregularity.

Table 4. Continued

10	Earthquake joint requirement	**X** Required (see A4.1)	**X** Required (see A4.2)	**X** Required (see A4.3)	**X** Required (see A4.4)
11	Expansion joint	— Not present.	— Not present.	— Not present.	— Not present.
12	Seating joint	— Not present.	— Not present.	— Not present.	— Not present.

Table 5. Evaluation of Compliance with Structural Requirements After Adaptive Reuse: B. Structural System

Code	Parameters	Compliance Check According to Structural Standards			
	Masonry and Steel Building	1. TBDY19	2. EC8	3. ASCE/SEI 7-22	4. General Principles
1	Building height limit	✓ 9,12 m<10,5 m 8,99 m<10,5 m	— No limit is specified.	✓ 9.12m<10.70m 8.99m<10.70m	✓ It is appropriate.
2	Storey height	✓ Wall strengthening improved the storey height factor.	✓ Wall strengthening improved the storey height factor.	✓ Wall strengthening improved the storey height factor.	✓ Wall strengthening improved the storey height factor.
3	Cantilever&span length	✓ 100 cm supported cantilever <150	— No limit is specified.	— No limit is specified.	✓ 100 cm supported cantilever <150
4	Existence of basement floor	**X** Partial basement present, not advised.	**X** Partial basement present, not advised.	**X** Partial basement present, not advised.	**X** Partial basement present, not advised.
5	Minimum wall thicknesses	✓ Each floor: 50 cm > 35 cm	✓ Each floor: 50 cm > 35 cm	✓ Stone: 50 cm> 40.6cm, brick: 50 cm > 20.3 cm.	✓ Each floor 50 cm > 50 cm
6	Maximum unsupported length of walls	**X** 7.87 m > 7.50 m (Ground floor)	✓ 7,87 m<15 m (15=wall thickness x 30)	✓ Wall length/wall thickness 7,87 m/0,50 m<20	✓ The lengths are within acceptable limits.
7	Total length limit of load-bearing walls	— No limit is specified in the standard.	— No limit is specified in the standard.	— No limit is specified in the standard.	**X** X direction 40,12/ 530 = 0.07 < 0.25
					X Y direction 100,33/530= 0.18< 0.25
8	Ratio of door/window opening lengths to wall length along the unsupported wall length	✓ Most favorable wall 0,90 m/7,87m= 0.11<0.40	✓ Most favorable wall 0,90 m<7,87 m/4	— No criteria are specified in the standard.	✓ There is a wall in accordance with general principles.
		X Most unfavorable wall 3,97 m/8,40m = 0.47>0.40	**X** 3,97 m>8,40 m/4	— No criteria are specified in the standard.	**X** Load-bearing walls should have low opening ratios
9	Distance between building corner and door/window opening	**X** The shortest wall length is 0.92 m < 1.00 m (1st floor).	✓ Min. length > Wall height / 5 0.92 m > 0.84 m	**X** Min. length > 3 x wall 0.92 m < 1.50 m	**X** It is not suitable.
10	Wall length between door/window openings	**X** Shortest wall length 0.53 m<1.50 m (first floor)	✓ Total of opening heights/wall thickness 4,02/10<30	**X** Min. length>6 x wall thickness, 0.53 m<3.00 m	**X** It is not suitable.

Table 5. Continued

11	Perpendicular intersecting walls and openings	**X** Shortest wall length 0.20 m<1.00 m	– No criteria are specified in the standard.	**X** Min. length>3 x wall thickness, 0.20 m<1.50 m	**X** It is not suitable.
12	Length of solid wall between openings	✓ Longest wall opening 2,55 m<3.00 m	– No criteria are specified in the standard.	– No criteria are specified in the standard.	✓ Longest wall opening 2,55 m<3.00 m
13	Vertical stability connections for loads/ reinforcement of the frame	– Steel diagonal bracing is recommended. Not present.	– Steel diagonal bracing is recommended. Not present.	– Steel diagonal bracing is recommended. Not present.	– Steel diagonal bracing is recommended. Not present.
14	Requirement for columns stronger than beams	✓ Columns are stronger than beams.	✓ Columns are stronger than beams	✓ Columns are stronger than beams	✓ Columns are stronger than beams
15	Frame continuity	✓ It is continuous.	✓ It is continuous.	✓ It is continuous.	✓ It is continuous.
16	Corrosion condition	– No criteria are specified in the standard.	– No criteria are specified in the standard.	– No criteria are specified in the standard.	– No criteria are specified in the standard.
17	Fire protection status	✓ Should be applied according to fire standards.	✓ Should be applied according to fire standards.	✓ Should be applied according to fire standards.	✓ Should be applied according to fire standards.

The steel elements designed for system reinforcement purposes in the structure were mainly balanced, and the existing structural problems were tried to be eliminated. The irregularity of the recesses and protrusions in the plan that existed before of the building continued to exist because the architectural design could not be interrupted. It is thought that the applied structural reinforcement design was beneficial in reducing the negative impact of this situation. The fact that the level differences of the slabs continued after reuse, a horizontal discontinuity situation occurred within the framework of all standards and general principles. However, it is thought that the negative impact was eliminated by the steel frame system implementations. The steel frame system elements were designed orthogonally; it has become compatible according to all three standards in this aspect. Besides, continuity was provided in the vertical structural elements. It is thought that adding a partial basement floor to the building in line with the architectural need might have triggered different torsional and vertical settlement possibilities. It should not be overlooked that the partial basement floor, which rises on a reinforced concrete raft foundation and is completed with reinforced concrete shear walls around it and a reinforced concrete slab on top, creates a structural difference in terms of rigidity between it and the section without a basement. During the restoration, because of the necessity of preserving the original design, no dilatation was designed between two masses. This separation is recommended for the different behavior of the two sections under seismic loads in all three standards, just as it was before the adaptive reuse. According to the structural analysis report, the height of the structure complies with the TBDY2019 and ASCEI-SEI 7/22 limits for both sections and the general principles, although no limit is specified in EC8. The height of the ground floor is above the floor height limit values determined in TBDY2019 and EC8 and remains within the limit values in ASCEI-SEI 7/22. With the support of the structure with a steel frame system after the adaptive reuse, this issue improved for all three standards. The 100 cm long cantilever is considered reasonable since it is below 150 cm according to general engineering principles. The problematic long facade of the first floor, was supported with steel frame elements and reinforced by adding a row of brick with CFRP/Glass Fiber Reinforced Polymer to its section and increasing the section size. Thus, the wall thickness has become compliant with all three standards, EC6 and ACI 530-13 determined as sub-standards and general principles. The largest unsupported length of the loadbearing walls has become compliant with EC8 and ACI 530-13 with the applications made after the adaptive reuse. The 7.87 m unsupported wall on the ground floor exceeds the 7.50 m limit of TDBY19 but is at an acceptable level. Regarding the total length limit of the load-bearing walls, the ratio of the load-bearing walls to the gross area of the building in both directions of the building is less than 0.25 on the ground floor. It is thougth that the steel frame system, glass fiber polymer reinforcement, and increased wall thicknesses positively contribute to this situation. When the criteria for door/window opening lengths along the unsupported wall length are examined, the 3.97 m long wall on the first floor of the building shows negative characteristics according to all standards and general principles. The minimum length between window/door openings is also not suitable. As identified through structural assessment, the irregularities are marked in Fig. 5 and Fig. 6.

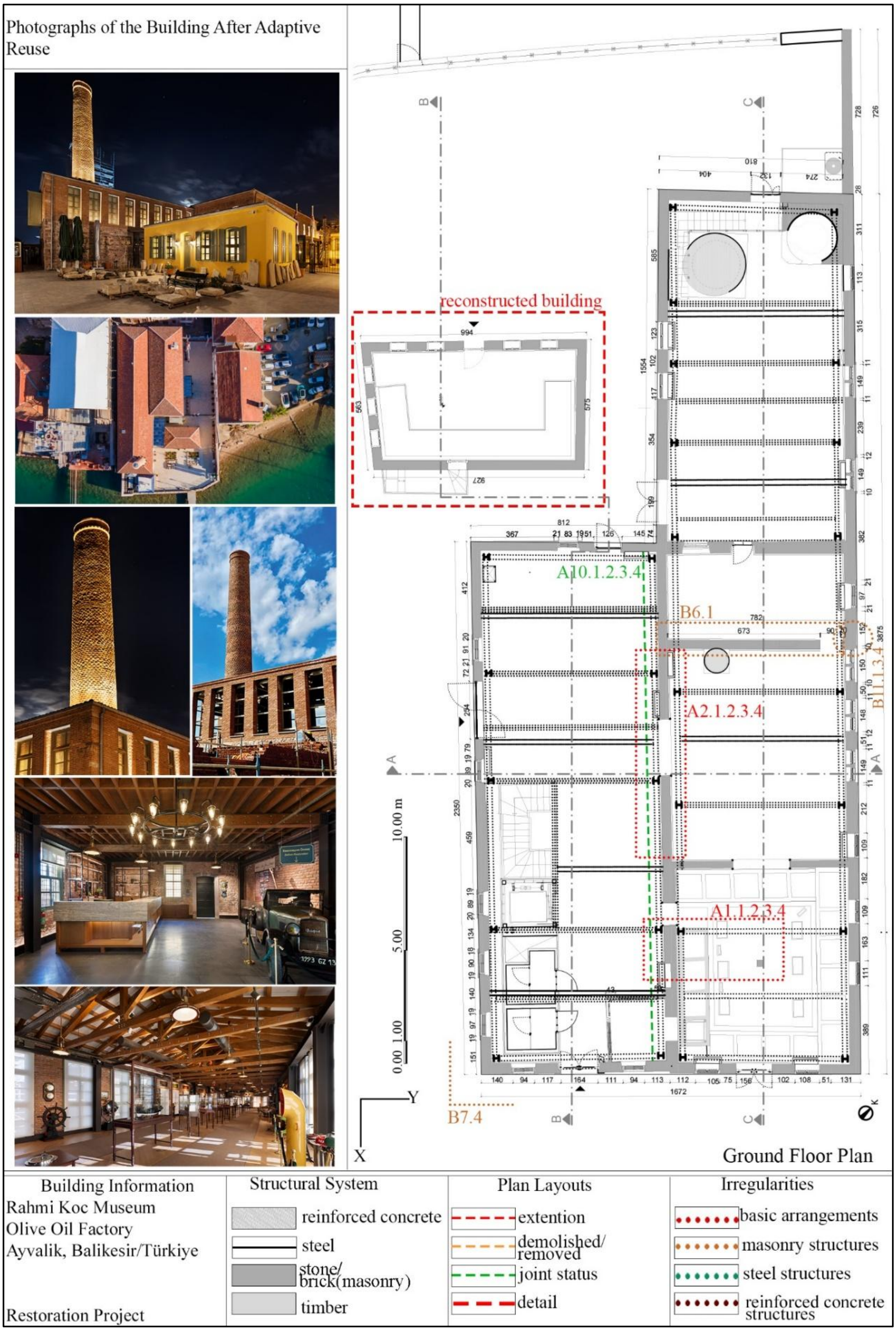


Fig. 5. Ground Floor Plan and Photographs (Modified by the author based on EMR Architecture, 2024.)

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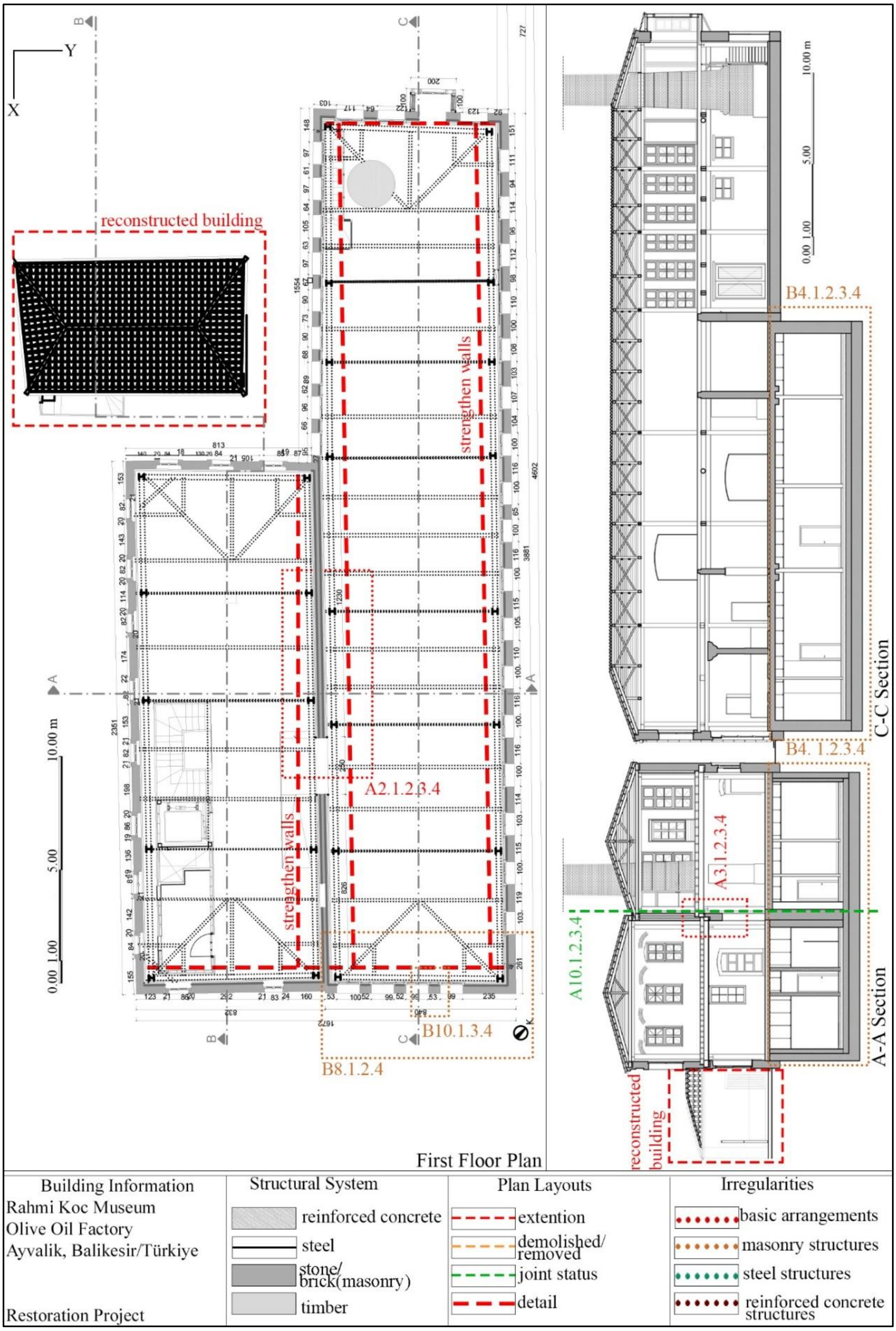

Fig. 6. First Floor Plan and Sections (Modified by the author based on EMR Architecture, 2024.)

4. Conclusions

After the Industrial Revolution, production methods changed in the world, and over time, small workshops were replaced by industrial buildings with wide open spaces using new building materials. However, these buildings were abandoned with the further development of technology and remained idle in the city. The idea of adaptive reuse of the industrial buildings, which are significant witnesses of the city's memory, has gained importance with the emergence of phenomena such as industrial heritage and conservation. The adaptive reuse concept aims to reintroduce these buildings to the city without losing their value.

Since most industrial heritage buildings have not received engineering services and have been exposed to many dangers over time, their structural systems can also be damaged. However, in the adaptive reuse processes of these industrial buildings, the applications should be reversible and should be carried out in a way that the buildings do not lose their authenticity. When the interventions made to the structural systems of industrial heritage buildings are also affected by the standards and regulations of the regions where the buildings are located. In this context, the building in research, which was previously used as an oil factory but is now used as a museum building, was evaluated with the approach of different regions of the world to structural system design and to what extent the building in question meets the principles of these regulations.

The original condition of the building presents many negativities in terms of TBDY2019, EC8, and ASCEI-SEI 7/22 standards and general engineering design principles. It is seen that some of these negativities continued after the adaptive reuse due to the necessity to remain as loyal as possible to the original structure and the inability to make extensive changes in the plan contours in order not to deteriorate the original architectural design.

The structural problems in the building have been mostly corrected and the building has become compliant not only with TBDY2019 but also with international standards by the steel frame applied to the building after the adaptive reuse. Although some irregularities and dimensional inconsistencies partially persist after the adaptation, the weaknesses have been largely eliminated with the addition of a steel frame system and glass fiber reinforcement to reduce the load on the masonry walls of the building, and it can be said that the overall performance of the building has been positively affected by strengthening the system statically and dynamically.

Acknowledgements

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Seismic characterization and vulnerability of stone masonry buildings in Urla

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Abstract. Stone masonry is one of the oldest structural materials used by humanity. Although the development of new building materials has reduced the use of stone masonry construction, in some regions it still constitutes a significant part of building stock. However, due to low tensile strength, high weight and the lack of maintenance, stone masonry buildings are known to be weak against earthquake loads. Furthermore, the use of different construction techniques and materials causes the seismic performance of the buildings to vary widely. Urla, located in the middle of Urla Peninsula, hosts many stone masonry buildings. The active seismicity and the high earthquake risk in the region pose a threat to stone masonry buildings. Therefore, it is crucial to evaluate seismic characterization and vulnerability of those buildings in Urla. To assess the seismic risk level in a region, rapid seismic assessment methods play the initial role since they allow to determine risk distribution quickly. In this study, the seismic performance of 30 stone masonry building in Urla is evaluated according to two rapid seismic assessment methods: FEMA P-154 and RBTE-2019. The performance scores of the buildings and the reasons behind the risk levels are presented in this paper.

Keywords: Building Stock; Rapid Assessment; Seismic Behavior; Stone Masonry; Urla

1. Introduction

Stone masonry buildings (SMBs) stand as one of the earliest building typologies used by humanity (Quelhas et al., 2014). Since the main material of SMBs, stone, is abundant across many regions in the world and these structures are characterized by ease of construction, SMBs can be broadly found throughout the world. It is also noteworthy that SMBs are known to have significant architectural and historical value and encountered mostly as cultural heritage buildings. Therefore, conservation approaches are common for these buildings (Gonen & Soyoz, 2021).

Stone masonry is composite structural materials consisting of stone and adhesive mortar in general, however, masonry walls without any adhesive materials (dry-joint masonry) are also seen in considerable numbers (Shantanu, 2020). Despite this simple definition, there is an extensive variability in the construction of masonry in terms of stone shape and size, bond pattern of the wall and presence of additional structural materials (Tomazevic, 1999). Construction traditions of nations, environmental and economic conditions have a great influence on wall construction. Stone type, used materials, and the typologies of flooring and roofing systems are shaped by the most abundant materials in the local conditions. Another aspect of variability is observed in wall construction, where stone walls can be built as single-leaf walls or as multi-leaf walls with infill materials. On the other hand, urban settlements and rural areas generally exhibit notable differences in the architectural characteristics of SMBs. Stone masonry structures are typically found as residential buildings in rural areas, whereas in urban settlements, they are more commonly seen as monumental and religious structures. Furthermore, SMBs in urban settlements are predominantly three or four stories high, whereas in rural areas, they are usually one or two stories (Tomazevic, 2014). Additionally, the size, complexity, and quality of construction in SMBs are generally greater in urban settlements compared to rural areas (Bothara & Brzev, 2012).

Stone masonry walls are known to be non-tensile structural elements due to their heterogeneous nature (Borri et al., 2020). Furthermore, diversity in construction of masonry walls leads seismic performance of these buildings to vary in a wide range, and complicates the understanding of its global behavior. Considering the characteristics of these buildings exhibits differences between region to region, inventory studies regarding classification of architectural and structural features of SMBs hold great significance (Tunc, 2024; Demir 2024). To better understand the seismic risk level of the buildings, rapid seismic assessment methods play the initial role. For large-scale of buildings stocks, it is not efficient and possible to analyze each building in detail, in terms of cost and time limitations. At this point, rapid seismic assessment methods allow prioritizing risk levels of buildings in short-time

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period. In this context, FEMA P-154 Rapid Visual Screening (RVS) (FEMA, 2015) stands out as one of the most commonly applied methodologies across the world, for various types of buildings. The method mostly focusses on the vertical and plan irregularities observed in the buildings. The method provides two levels of scoring scheme, requiring different information levels. Although this methodology is not oriented to masonry buildings and includes only a few parameters specific to masonry buildings, it includes a scoring section for unreinforced masonry buildings (URM) which estimates probability of collapse for masonry buildings. RBTE-2019 method (Provisions for the Seismic Risk Evaluation of Existing Buildings under Urban Renewal Law) has been published as a rapid approach to prioritize seismic risk levels of reinforced concrete and masonry buildings in certain regions of Türkiye. The section for masonry buildings in this method includes more parameters specifically regards possible deficiencies that can be observed in masonry buildings. Several rapid seismic assessment methods specifically related to masonry buildings can be found beyond the literature (Gatti, 2024; Islam et al, 2024; Ortega et al., 2019; Borri et al., 2015; Restrepo-Velez & Magenes, 2004). Application of these methods simplifies and accelerates risk mitigation efforts for urgent scenarios in seismically active regions.

Aegean shores of Türkiye is known to be one of the most seismic-active regions across the world. Almost 700 earthquakes bigger than Mw>4.0 have occurred in this region since 1900 (Çınar et al., 2021). In a narrower sense, series of significant earthquakes were felt in Izmir, which is the biggest city in Aegean shores, including Seferihisar 2005 earthquake Mw=5.7, Karaburun earthquake 2017 Mw=6.2, Samos earthquake Mw=6.6 (Binici et al., 2022). The increasing seismic activity gave rise to the need of studies regarding estimating the risk level of building stock across the city. Consequently, a comprehensive inventory study has been conducted in collaboration with Izmir Metropolitan Municipality and Bogazici University, results were presented in the report named Izmir Earthquake Master Plan (IDMP). The study was conducted in the central districts of Izmir, to clarify buildings typologies and related risk levels for those buildings. IDMP report have indicated that %11 of the examined 217824 buildings were masonry buildings, and also it was stated that the group of masonry buildings constitutes the most vulnerable buildings among all building typologies. Kahraman et al. (2013) conducted another comprehensive inventory study in Balçova and Seferihisar districts of Izmir, including 10550 buildings, indicating similar results with IDMP. Although these studies include numerous buildings, no inventory study has been conducted in Urla district, which is known to be with its diverse historical background. Furthermore, remarkable numbers of SMBs can be found in Urla, both in rural and urban areas of the district. Considering the diversity of SMBs in Urla, and low earthquake performance of these building typology, vulnerability assessment studies hold a significance. In relating to that, 30 SMBs in Urla were examined through site surveys in scope of this study. Subsequently, architectural and structural features of these buildings were classified, and their seismic performance were assessed through two rapid seismic assessment methods: FEMA P-154 and RBTE-2019, results are discussed and presented in this paper.

2. Site Surveys and General Observations

Urla is located in the center of Urla Peninsula, the south part of Izmir. It is the biggest district of Urla Peninsula with its population of 77599 and surface area of 704 km² (TUIK, 2023). Although its population is not as high as the population of central districts of Izmir, Urla constitutes a notable part of Izmir's geography. Including the central neighborhoods, a total of 37 villages and neighborhoods are involved in Urla (IDA, 2014). In scope of this study, several neighborhoods in Urla were visited and a total of 30 SMBs were examined on-site, including not residential ones but also educational, religious and commercial purposed buildings. The geographical distribution and occupancy classes of 30 examined buildings is shown in Fig. 1. Data regarding the buildings' occupancy classes, age, wall texture, stone and mortar type, diaphragm type, presence of bond beams and lintels, situation of restoration and presence of existing damage were collected using a data collection sheet prepared in scope of this study. Furthermore, a measurement survey was also conducted, and plan and elevation drawings were also drawn during site visits.

The SMBs in Urla were found to be box-type, simple buildings. Examined buildings were mostly 1 or 2 floors, except a three-storey building in Gülbahçe village. Data related to construction data of the buildings was obtained through oral conversations with building owners, and it was found that the buildings were considerably old, with an average age of 78. Religious buildings, three mosques in this study, were found as oldest structures with most eligible architectural and structural features. It was observed that stones were obtained from local quarries by the self-effort locals of the villages in rural areas. However, it was noted that stones of the buildings in central settlements of the district were obtained from industrial quarry located in Balıklıova. Stone masonry walls were generally found to be constructed as rubble in texture and thick in size. Mud and lime-based mortars were common in these buildings. One critical observation was that the SMBs in this region were mostly constructed with timber floors. Rigid diaphragms, reinforced concrete slabs, were found only in 4 buildings. Bond beams (*hatıl*) were found to be present %26 of the 30 buildings. While buildings are mostly in detached position in rurals, buildings attached to neighboring buildings were rather common in central neighborhoods of Urla. Examples of examined SMBs are shown in Fig. 2.

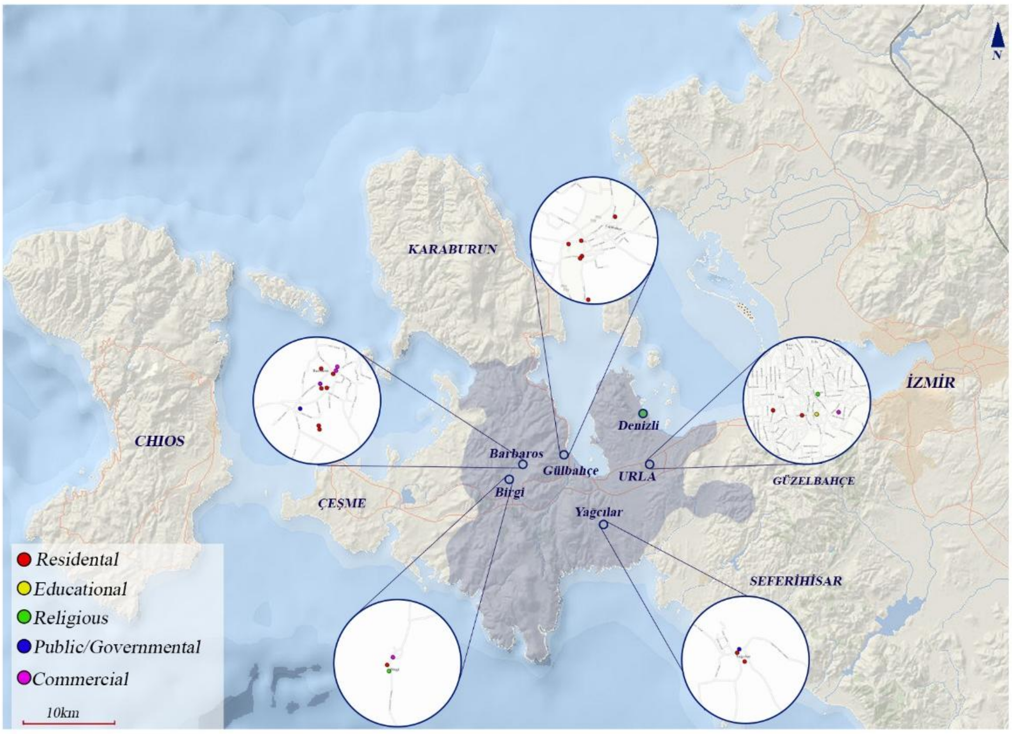

Fig. 1. Distribution of examined buildings with occupancy classes.

Fig. 2. Examples of examined buildings, a) Gülbahçe, b) Barboros, c) Birgi villages.

3. Rapid Seismic Assessment

Vulnerability scores of 30 SMBs were evaluated through the methods of FEMA P-154 and RBTE-2019, using the data collected from buildings, plan and elevation measurements and photographs taken on-site. Assumptions, scoring process and results are presented in the related subtitles of the paper.

3.1. FEMA P-154

FEMA P-154 Rapid Visual Screening method (FEMA, 2015) has been published by Federal Emergency Management Agency, to estimate seismic hazard for large numbers of buildings. The method only requires visual on-site inspection of a screener, which is not expected to exceed 15 minutes. The method mostly considers the possible architectural irregularities in buildings and does not require measurements. Two levels of scoring schemes are provided in this method, Level 1 and Level 2 scoring, and each can be applied for 17 types of structural system. Considering that all of the examined buildings are unreinforced stone masonry, scoring for only unreinforced masonry buildings (URM) was used in this study. However, scoring schemes vary depending to the seismicity level of the region. The method divided seismicity regions into five levels, and different scoring forms are provided for each seismicity level. Determination of seismic level for the building site is made according to short-period spectral acceleration (S_S) and 1-second spectral acceleration (S_1) values expected for the region. These values were obtained from Turkish Seismic Hazard Map published by Disaster and Emergency Management Authority of Türkiye (AFAD, 2018), using the occupancy classes of each building and soil type of the building sites. Since the data related to soil type could not be obtained, it was assumed that all soil types are "D" class, as it is directed in the FEMA P-154 handbook (FEMA, 2015). Although RVS forms provides nine different occupancy classes, this classification was made according to Turkish Building Earthquake Code (TBEC, 2018), since the hazard map follows this code. The determination of seismicity level using the S_S and S_1 values are shown in the Table 1.

According to provided classification, 28 buildings were found to be in High seismicity region, while the remaining two buildings were found to be in Very High seismicity region.

In each scoring, Level 1 and Level 2, basic scores are assigned to buildings, according to the seismicity level of the buildings' region. Final Level 1 score (S_{L1}) is calculated by summing the basic score and modifiers, which represent negativeness parameters in buildings. One of these parameters is that vertical irregularities might occur in URM buildings. Vertical irregularities (V_{L1}) are estimated in two conditions, severe or moderate. If the ground floor of the buildings is higher than the upper floors, this condition is considered to be presence of soft storey, a type of severe V_{L1}. Less amount of wall in ground floor leads to weak storey, another type of severe V_{L1}. Out-of-plane setbacks are also considered as severe V_{L1}. Sloping sites create a one-storey level difference between two facades of the building, level differences of slabs in a building and in-plane setbacks are considered as moderate V_{L1}. If load-bearing walls in two directions are not well-distributed in plan layout, this situation may lead to a torsional weakness for the building and considered as plan irregularity (P_{L1}) in FEMA P-154 Level 1 scoring. The presence of reentrant corners and diaphragm opening exceeding half of the whole diaphragm are also considered P_{L1}. Since the soil types are assumed to be "D" class, modifiers relating A-B and E type were not applied to any buildings. Post benchmark and pre-code modifiers are not considered for Level 1 scoring in High and Very High seismicity zones. Basic scores and values of modifiers for High and Very High seismicity regions are shown in Table-2.

Base score for Level 2 scoring is determined by subtracting V_{L1} and P_{L1} modifiers from S_{L1}, since these parameters are considered again in Level 2 scoring. Level 2 scoring estimates vertical and plan irregularities in separated subtitles. Additionally, presence of gable walls, pounding effect for attached buildings and retrofitting implementations are also considered in Level 2 scoring. Evaluating of 30 buildings in Level 2 scoring are applied as directed in FEMA P-154 handbook (FEMA, 2015). RVS provides minimum scores for both Level 1 and Level 2 scoring, which is 0.2 for URM buildings. However, to estimate the vulnerability level of each building and establish a comparative result, the minimum score guidance was not applied in this study, for each scoring of RVS.

Table 1. Determination of seismicity level according to FEMA P-154.

Seismicity Level	**S_S**	**S_1**
Very High	$S_S \geq 1.500g$	$S_1 \geq 0.600g$
High	$1.000g \leq S_S \leq 1.500g$	$0.400g \leq S_1 \leq 0.600g$
Moderately High	$0.500g \leq S_S \leq 1.500g$	$0.200g \leq S_1 \leq 0.400g$
Moderate	$0.250g \leq S_S \leq 0.500g$	$0.100g \leq S_1 \leq 0.200g$
Low	$S_S \leq 0.250g$	$S_1 \leq 0.100g$

Table 2. Basic scores and modifiers in Level 1 Scoring (Adopted from FEMA, 2015)

Parameters	**Basic Score and Modifiers**	
	High	**Very High**
Basic Score	1	0,9
Severe V_{L1}	-0.7	-0.6
Moderate V_{L1}	-0.4	-0.3
P_{L1}	-0.4	-0.3
Post-Benchmark	NA	NA
Pre-Code	0	0
A-B Soil Type	0.3	0.1
Soil Type E (1-3 Floors)	-0.2	0

3.2. RBTE-2019

Provisions for the Seismic Risk Evaluation of Existing Buildings under Urban Renewal Law (RBTE-2019) was published by Turkish Ministry for Environment and Urban Planning to range buildings according to seismic hazard level, including masonry buildings. This method is also known as rapid, first stage screening for buildings, however, it includes more parameters and requires basic measurements for masonry buildings. As it is directed in FEMA P-154, the first step of RBTE-2019 is determining the seismicity zone of the building site. Differing from FEMA P-154, seismicity level of the building site is determined according to spectral design acceleration (S_{DS}), which is the multiplied version S_S with soil type coefficient. The values of S_{DS} are obtained, again, from the Turkish Seismic Hazard Map (AFAD, 2018). All of the soil types are assumed to be "ZD" (refers to D in FEMA P-154) to ensure consistency between to methods. Occupancy classes are determined as it is directed in TBEC (2018). The method has similar approach with FEMA P-154, assigns each building a base point (BP) according to the seismicity level of the building site. BP for soil type ZD and S_{DS} values are given in Table 3.

Table 3. Determination of base point according to soil class and S_{DS}, for RBTE-2019.

Seismicity Zone	Soil Class	S_{DS}	Base Point		
			1-Storey	2-Storey	3-Storey
1	ZC/ZD/ZE	≥1.0	110	100	90
2	ZC/ZD/ZE	$1.0 \geq S_{DS} \geq 0.75$	120	110	100
3	ZC/ZD/ZE	$0.75 \geq S_{DS} \geq 0.50$	120	110	100

Masonry buildings are divided into four typologies in RBTE-2019 guideline and different structural system points (SP) are assigned to these typologies. Since the examined buildings consist of only URM buildings, SP was assigned as 0 for all buildings. Fifteen negativeness parameters are provided in RBTE-2019. Conditions for parameters are related with numeric values, parameter values ($_i$). Positive conditions are linked to 0 parameter value, while moderate and bad conditions are linked to 1 and 2 parameter values, respectively. Additionally, parameter points (NP_i) are also assigned to each parameter. All parameters, numeric representations for parameters and parameter points are shown in Table 4. Certain parameter points varies according to the number of floors of the buildings. Performance Point (PP), which is the final assessment score for this method, is calculated by Equation 1.

While assessing the material quality, masonry walls built with rounded, riverside stones and small uncoursed stones were assumed to be bad quality. Walls constructed with partially coursed stones are assumed to be average and walls with cut-stones are assumed to be good quality of material. Determining masonry workmanship quality is also defined with three conditions. Masonry walls constructed with staggered vertical joints and continuous horizontal joints are assumed to be good quality. If load-bearing stone masonry walls are totally irregular in terms of vertical and horizontal joints, this situation is considered to be bad quality, and all other cases are assumed to be average workmanship quality. It was assumed that slab levels of attached buildings are different, which means pounding effect is assumed to exist for all attached buildings. The remaining parameters are evaluated as it is directed in the RBTE-2019 guidelines.

$$PP = BP + SP + \sum(N_i \times NP_i) \quad \textbf{(1)}$$

Table 4. Parameters,

Parameters		Numeric Representations of Parameter Values			Parameter Point for Number of Floors		
		0	1	2	1	2	3
Building Alignment		Detached	Attached	-	-	-	-
Material Quality		Good	Avg.	Bad	-10	-10	-10
Masonry Workmanship		Good	Avg.	Bad	-5	-5	-5
Existing Damage		No	Yes	-	-5	-5	-5
Plan Geometry		Regular	Irregular	E. Irregular	-5	-10	-10
Bond Beam (*hatıl*)		Presence	Absence	-	-5	-5	-5
Amount of Wall		High	Avg.	Low	-5	-5	-10
Opening Regularity		Regular	Partially R.	Irregular	0	-5	-5
Level Difference		No	Yes	-	-5	-5	-5
Soft/Weak Storey		No	Yes	-	0	-5	-5
Out-of-Plane	Slab Type	R.C.	Other	-	-10	-10	-10
	Wall-to-Wall	Good	Bad	-			
	Wall-to-Slab	Good	Bad	-			
	Mortar Type	Cement	Other	-			
Roof Material		Other	Earthen	-	-10	-10	-10

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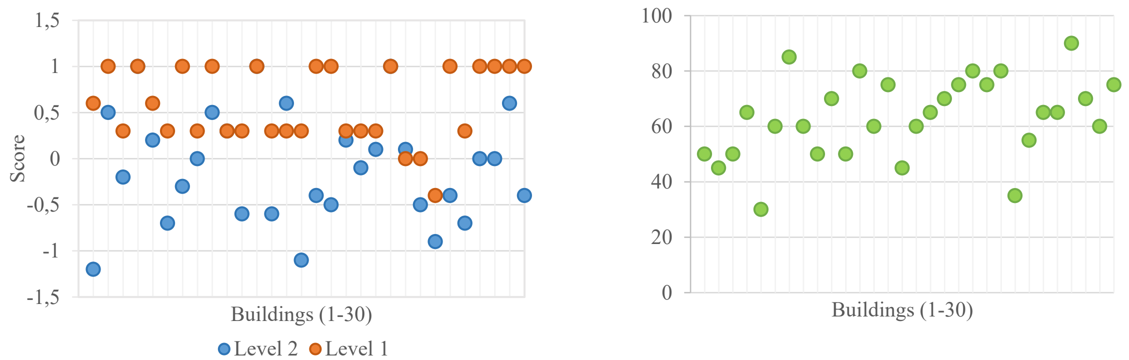
4. Results and Discussions

Final scores obtained from FEMA P-154 Level 1 and Level scoring are shown in Fig. 3a. The results indicates that notable part of the buildings were not punished by negativeness parameters. Another notable part of the buildings were modified with severe V_{L1}, as a result these buildings were clustered in 0.3 points. Results of Level 2 scoring differ notably from Level 1 scores. More detailed estimation revealed the deficiencies in the buildings as clustering buildings' scores under zero points. The parameter related to pounding effect, which is included in Level 2 scoring but not in Level 1 scoring, led buildings to get less points in Level 2 scoring. The presence of gable walls were not considered in Level 1 scoring, however, this parameter also caused buildings to get less points in Level 2 scoring.

Performance scores obtained from RBTE-2019 are mostly clustered in the mid-ranges, shown in Fig. 3b. The most impactful parameter is material quality in this method, and it was seen that buildings with "bad" material quality could not exceed 60 points. Another crucial parameter is out-of-plane behavior of the masonry buildings. The condition which led buildings to have bad out-of-plane response is mostly the absent of rigid diaphragm. Buildings with rigid diaphragm were found to have performance points not falling below 80 points. It should be noted again that that number of buildings with rigid diaphragms are scarce in this building stock. Pounding effect stand as another crucial parameter, as it is observed in FEMA P-154. Attached buildings, where pounding effect exists, is failed to exceed 70 points, since this parameter is one of the most impactful parameters in the RBTE-2019 methodology. However, it should be noted that the buildings carrying the risk of pounding effect are rather scarce in these buildings.

In order to compare the final assessments scores obtained from each method, Final Level 1 and Final Level 2 scores from FEMA P-154 and Performance Points obtained from RBTE-2019 are normalized to a 0-100 scale. Normalized final assessment scores of each building is shown in Fig. 4. It is observed that Final Level 1 scores are beyond any correlation with both Final Level 2 scores and RBTE-2019 scores. Final Level 2 scores and RBTE-2019 scores are partially correlated with each other, however, average RBTE-2019 score is clearly higher than FEMA P-154 Level 2 scores. This situation can be explained with the plurality of the parameters in RBTE-2019 provide to estimate positive features of these buildings such as sufficient amount of walls, regular plan and opening layout.



a) b)

Fig. 3. Final assessment scores, a) FEMA P-154 Level 1 & 2, b) RBTE-2019.

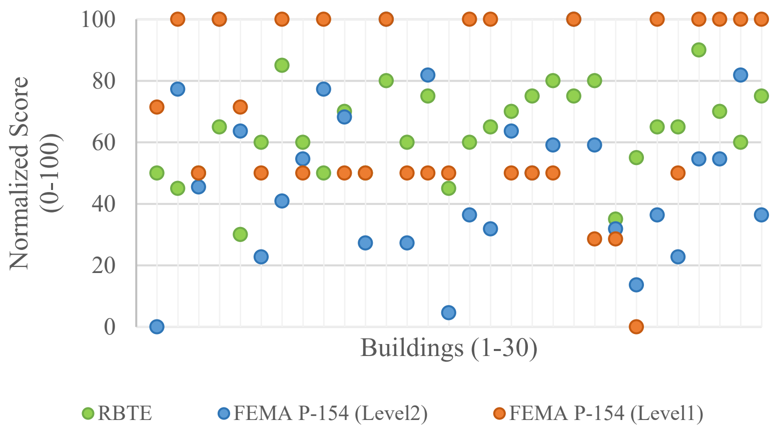


Fig. 4. 0-100 Normalized final assessment scores obtained from each method.

5. Conclusions

In this study, a total of 30 SMBs in Urla were examined on-site and their general architectural/structural features are presented. In the subsequent phases of the study, seismic risk level of these buildings were evaluated using two rapid seismic assessment methods: FEMA P-154 and RBTE-2019. SMBs in Urla are mostly observed to be small, box type, one or two floors and relatively old buildings. Masonry walls are generally constructed as rubble masonry with partially coursed stones. Rigid diaphragms and bond beams were barley found in this building stock.

Seismic performance of these buildings exhibited variety in a wide range according to each method. Final Level 1 score of FEMA P-154 was not distributed in a meaningful range, while Final Level 2 scores showed the vulnerability of these buildings more clearly. The reason behind lower Level 2 scores can be explained with the parameters included in Level 2 scoring but not in Level 1 scoring, such as pounding effect and presence of gable walls. RBTE-2019 scores clustered in the mid-range. The results of this method indicate the importance of masonry wall quality, diaphragm typology and building adjacency. It is suggested that the risk mitigation efforts have to specifically prioritize the buildings with the following character:

- SMBs with rounded, uncoursed, totally irregular masonry walls
- SMBs where there is a possible pounding effect
- SMBs without any rigid floor diaphragm

It is also expected that the inventory and risk estimation studies will be enlarged with extensive numbers of buildings spreading across larger regions.

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Structural damages of Van Ernis Village Institute buildings

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Abstract. Village Institutes were institutions established in the first years of the Republic, with the aim of building a nation-state, as well as aiming to develop and raise awareness of the people in the country where most of the population lived in villages, aimed at their socio-economic progress, and also provided the education of village children. For this purpose, these institutes have been established in almost every region throughout Türkiye, in places where several cities are combined.One of these institutes that left its mark on a period and still maintains its importance on the agenda is Van Ernis Village Institute. Van Ernis Village Institute campus is the 21st Village Institute to be opened recently. It is 80 km from Van, 18 km from Erciş district, 24 km from Muradiye district, in the form of a peninsula surrounded by Lake Van on three sides, in an area of approximately 150 decares. Like other village institutes, Van Ernis Village Institute is a campus that includes many structures such as dormitory, dining hall, workshops, classrooms, library, bathhouse and administrative units. This campus, which was in active use since 2011 in accordance with its educational function, was abandoned after the 2011 earthquake in Van and its surroundings. Determining the structural damage of the surviving buildings in this campus today constitutes the purpose and scope of this study. Field observation, on-site measurement and documentation systems were used as the study method. This study aims to contribute to the documentation and transfer of the Van Ernis Village Institute campus, one of the first institutions of the Republic in Van, to the future.

Keywords: Village institutes; Van Ernis Village Institute; Van Earthquake; Structural damages

1. Introduction

Village Institutes were institutions established in the early years of the Republic to build a nation-state, and also to develop the people, raise their awareness, and ensure their socio-economic progress in a country where most of the population lived in villages, and to provide education for village children. For this purpose, these institutes were established in almost every region of Turkey, in places where several cities meet. In these institutes, the aim was to provide students with the ability to solve problems they would encounter in real life, as well as to contribute to the development of the villages they were in, and the education program was organized and implemented in the form of learning by applying on-site. These village institutes, which were opened in 21 units throughout the country, were later closed by the decision of the political structure of the period. One of these institutes that left its mark on a period and still maintains its importance on the agenda is the Van Ernis Village Institute. The Van Ernis Village Institute is the 21st institute that was recently opened (Figure 1). Village Institutes were institutions that were generally organized as a campus and included many structures such as dormitories, dining halls, workshops, classrooms, libraries, baths and administrative units. The locations chosen on the campuses, the local materials they were made of and their dimensions varied according to the function of each structure.

The Ernis Village Institute, like other village institutes, is a settlement that contains many structures. The institute, which contains many large and small buildings for education, accommodation and other needs, was left dysfunctional and to its own fate for many years, and when it was defeated by time, most of the structures were demolished, and the ones that remained standing were damaged and managed to survive to the present day. In recent years, a section of the campus was allocated to a tourism business, and nine of the remaining structures were registered.

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Fig. 1. Village Institutes in Türkiye

This campus, which is considered to be transferred to the Ministry of Youth and Sports, was taken as a subject of study because it is one of the architectural heritages of the Republic period and because it is an important place in terms of education. The aim is to both draw attention to the institute by determining the architecture and existing damages of the structures in this campus, document them and create a basis for possible future plans.

The Village Institutes, established in Turkey in the 1940s, aimed to provide teachers with the theoretical and practical training they needed to solve various problems in the villages where they would work and to increase the productivity of the village. The Village Institute Project was part of a populist ideology that aimed to eliminate the inequality of opportunity between urban and village life. In other words, the Village Institutes were considered a tool to create and spread the national culture of the newly established Republic of Turkey (Aytemur, 2007).

In Turkey, while 75% of children living in cities attended primary school between 1933-1934, only 20% of village children could benefit from primary school education, efforts to expand education gained momentum between 1936-1939 and four Village Teacher Training Schools were established. These four schools were the first steps of the Village Institutes Project developed and put into practice by the Minister of National Education at the time, Hasan Ali Yücel, and the General Director of Primary Education, İsmail Hakkı Tonguç. With the new laws put into effect for the new education system, Village Institutes began to be established, and it was aimed to create a new organization in education suitable for the village structure and to give a new task definition to the village school and its teachers. Thus, the "village revitalization policy" adopted by the Village Institutes was legally secured, and by the end of 1948, the number of village institutes throughout Turkey had reached 21. The last institute to open was the Van Ernis Village Institute. Among these, the Ernis Village Institute, established 80 km away from Van in 1948, started education with the logic of learning by doing in order to train teachers for the surrounding provinces.

Following the transition from a single-party system to a multi-party system in 1946, within the framework of Law No. 6234 dated January 27, 1954, it was accepted that Village Institutes would be called 'primary teacher training schools', and students in these closed educational institutions, such as the Van Ernis Village Institute, continued their education in these campuses, which were transformed into schools implementing a different education system, or in different schools.

1.1. Purpose

Within the scope of this study, it was aimed to make an ecological assessment of the three surviving structures in the Van Ernis Village Institute, and also to examine and examine the architectural projects and damage status of these structures. As a study method, observation, examination and on-site measurements were made in the field, and literature data on the subject was examined. One of the study purposes is to bring to light one of the main sources related to the Village Institutes, one of the most original projects in the history of the Republic in Turkey. Another purpose is to address the current problems of this campus, which is a beautiful example of the architecture of the Republic period, and to ensure that precautions are taken against possible damage to the structures in the future.

2.2. Method

In the study, in addition to literature review, observation and in-depth examination and project design methods were applied in the field. In terms of content, first the village institutes and then the Van Ernis Village Institute were examined. Then, ecological data were taken from 5 buildings in this institute. Again, structural damage and problems in these buildings were determined by on-site observation in the field. In the research conducted on village institutes, it is possible to come across many literatures. Many theses, articles and studies have been conducted on 21 village institutes in Turkey. However, the studies conducted on Van Ernis Village Institute are extremely limited and currently, they are mostly seen in the form of news in the media.

There are many master's and doctoral theses conducted on Village Institutes in different disciplines and architecture. Some of these, especially in the discipline of architecture;

Baysal, E. (2006), “View of village space in the Early Republican Period and spatial experiences in village institutes”; Aladağ, A. (2019) “Preservation of village institutes as cultural heritage sites in the Early Republican Period; The example of İvriz Village Institute”; Yeşiltepe, A. (2022), “Traces of modernization in rural areas: A study on the heritage values and protection of village institute campuses”.

Another study on village institutes is the study of Figen Kıvılcım and Çakıcı (2013) titled “History and Values of Hasanoğlan Village Institute and High Village Institute Campus” published in an architecture journal.

It is possible to list many more publications on this subject. However, the studies on the Van Ernis Village Institute are extremely limited and are first included in a few pages in the book titled “Village Institutes in Turkey” prepared by Fay Kirby (1962).

One of the studies on this institute was presented by Subaşı Direk (2023) under the title “Van Ernis Village Institute Campus” in Local Expansions of Modernism in Turkish Architecture XIX (Docomomo 2023).

Village institutes included buildings made mostly by students using local materials from the region and environment in which they were located. These materials were generally stone, wood and soil. Within the scope of the study, three structures were examined in the Van Ernis Village Institute, and it was determined that these structures and other structures used throughout the campus were also made of these natural materials.

2. Van Ernis Village Institute

Van Ernis Village Institute is a settlement that started to be used as a Village Institute in 1948, but in fact the structures inside were built and used much earlier. The settlement is located on the northern tip of Lake Van, 80 km from Van, 18 km from Erciş district, and 24 km from Muradiye district, on an area of approximately 150 acres. It is located on a peninsula surrounded by Lake Van on three sides.

The settlement, which contains around 30-40 large and small structures, was first used as a Russian shipyard and then as a military barracks. No information has been found regarding the architects or engineers of the structures in the campus.

It was opened in 1948 as a Village Institute, under the Ministry of National Education at the time, and was soon converted into a Village Teachers' School, then into Ernis Primary Teachers' School, Alpaslan Primary Teachers' School, Muradiye Alpaslan Anatolian High School and finally Muradiye Alpaslan Science High School, and was used as an educational campus until 2011. The campus was abandoned after the 2011 earthquake in Van and its surroundings, when the buildings on the campus were damaged and some of them collapsed (Fig. 2-3).

Fig. 2. General situation of Van Ernis Village Institute Campus (Recreated by the author via Google Earth, 2023)

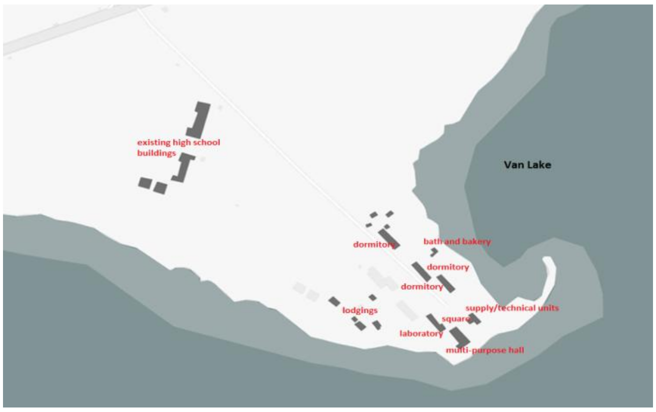

Fig. 3. Sketch of the location of buildings in Van Ernis Village Institute Campus

Some of the campus structures were built by the Russians as shipyards and service buildings until 1915. Later, it was used as a military barracks and some dormitories and service buildings were added during this process. When it was opened in 1948 as the last and 21st of the Village Institutes, the students of the Institute first built the oven and bathhouse with their own means. This bathhouse structure, made of Ahlat stone, a building material of the region, is important not only because it is the only structure that still stands almost undamaged, but also because it is one of the first structures built by the students of the institute with their own means (Fig. 4).

Another building on the campus, which was used as a workshop for a while and later as a dormitory when the number of students increased, and a multipurpose hall are also made of stone. These structures are discussed separately. Ahlat stone, scientifically known as "ignimbrite", is extracted from the foothills of Mount Nemrut in the Ahlat district of Bitlis. Ahlat stone is a volcanic rock. Due to its durability, ease of processing and prevalence, it has been used in many structures in the region, especially historical monuments. Ahlat stone, which usually has different colors such as white, cream, gray and coffee, is a building material still used in structures in the region. The surface of this stone is rough and is known for its high durability. Ahlat stone has a specific gravity of 2.6-2.64 and a compressive strength of around 14 Mpa (Işık, 2007).

Fig. 4. Location of buildings in Van Ernis Village Institute Campus

2.1.Van Ernis Village Institute Bath Structure

The bath structures of village institutes were buildings built to meet the cleaning and hygiene needs of users in these schools. Baths were used to meet the cleaning needs of students and staff, to provide a hygienic environment and to prevent health problems. The bath structures of village institutes generally had a simple and functional design. They were mostly built as stone or brick structures. Hamams usually consisted of a changing room (cold) and a washing room (warm). Hamams were used to provide health education as well as meeting the hygiene needs of students and staff. Cleaning habits, body care and hygiene were taught in hamams.

However, after the end of the village institute period, many village institutes were closed or used for different purposes. Therefore, today, village institute baths are generally dysfunctional or unrestored.

Van Ernis Village Institute Bathhouse is located in the northwest part of the peninsula-shaped settlement surrounded by a lake on three sides, which started to be used as a Village Institute in 1948. It is important as it is one of the first structures built by the students of Ernis Village Institute, the 21st and last of the Village Institutes, with their own means. It is also one of the structures that managed to survive the last major earthquake in the region. While other structures were severely damaged and most of them were destroyed, the bathhouse, which was built with a masonry system and the local material Ahlat stone, is still standing solidly (Fig. 5). It is possible to see the different colors of Ahlat stone, which is a volcanic stone, on this bathhouse.

The Van Ernis Village Institute Bathhouse structure consists of two sections. The first section is the dressing and preparation (cold) section, with a clean opening of 5 m x 7 m, four windows on each side, and a door in the middle of the southeast section to enter the space. The second section of the bathhouse structure is the washing (warm) section. There are toilets on both sides between the hot section and the preparation section of the bathhouse (Fig. 6).

The cold section, which is passed through a hipped roof, is accessed through a door that is exactly in the middle, to the hot section. The square hot section, which has an interior opening of 6.4 m x 6.4 m, has arches on its four sides. There are three basins inside each arch (Fig. 7). In the very center of the bath, there is an eight-sided navel stone and a dome on it that is as wide as the bath. There are lighting holes called elephant eyes on the dome that provide illumination to the interior. In order to heat the bath, which was built with extremely neat workmanship, a section called the furnace was built between the bath and the oven. The oven is located in the northwest part of the bath. It is thought that the heat in the furnace was also used for the oven.

Fig. 5. Van Ernis Village Institute Bath

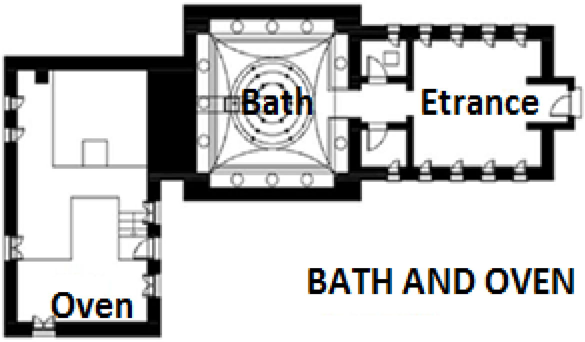

Fig. 6. General plan of Van Ernis Village Institute Bath

Although no serious damage was observed in the measurements made on the bath structure, there are some deteriorations in places due to plant growth, lack of maintenance due to long-term disuse and gradually water-humidity and lack of maintenance in the materials. It is known that the Ahlat stone used in the structure has low durability and wears out a lot due to its soft spongy feature, therefore temperature differences, frost and humid environments affect this situation and cause fragmentation and breakage. Freezing and thawing, which is effective cyclically especially in cold periods, is one of the most important factors in the deterioration of the building stones in the region.

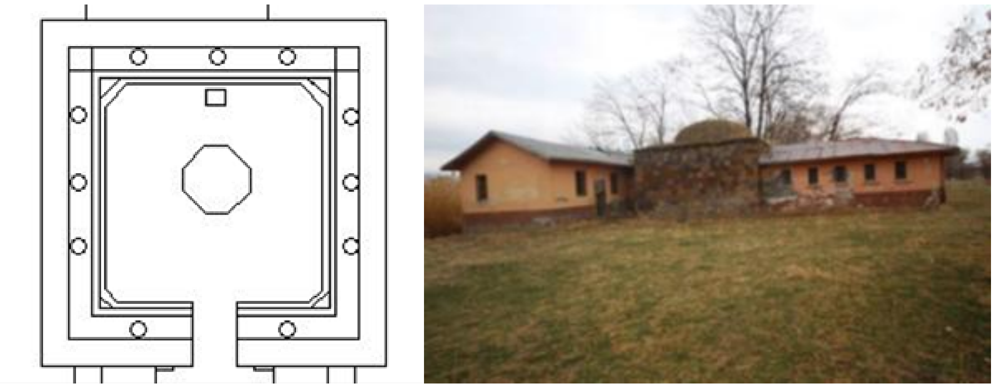

Fig. 7. Van Ernis Village Institute Bath Hot Section Plan and View

2.2. Van Ernis Village Institute Dormitory

The dormitory has a rectangular plan in the east-west direction. The entrance to the building is provided by a rectangular door in the middle of the south facade. There is a two-step staircase in front of the door. A square hall was created at the entrance, and the hall divided the two areas built in the same arrangement in the east and west of the building in the middle. There is a square-plan room on the north of the hall on the entrance axis (Fig. 8). The east wing and west wing of the building are accessed by one door in the hall. After passing through the door, there are large dormitory areas on both wings and two rooms in the corners of the dormitory. In the dormitory sections, there are two pillars located on the same axis to support the upper cover.

A total of twelve supporting piers were used, six on each of the north and south facades of the building. The piers continue from the ground to the ceiling level and support the upper cover. There are thirty-eight window openings in the building, sixteen on each of the north and south facades and two on each of the east and west facades. In this way, the building has a very spacious appearance (Fig. 9). Stone material was used as construction material in the building. The building is covered with a hipped roof covered with metal sheet.

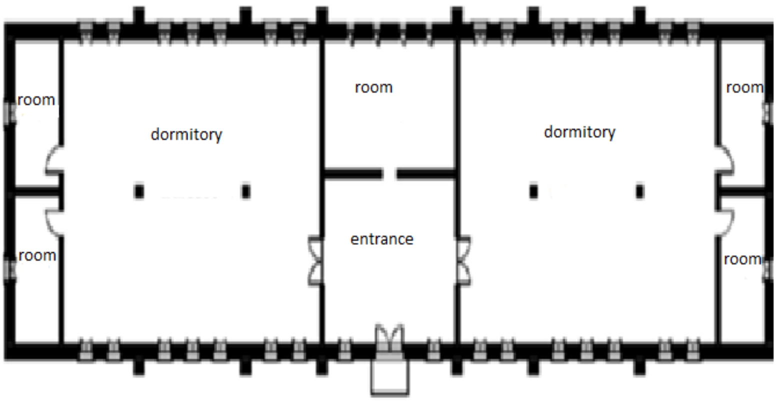

Fig. 8. Van Ernis Village Institute Dormitory plan

Fig. 9. Van Ernis Village Institute Dormitory view

This building, which was thought to have been used as a workshop and then as a dormitory, shows peeling paint and plaster, some deterioration due to water from the ground, and some damage to the windows and walls due to not being used for a long time when viewed from the exterior. However, this building, which has an intact facade, is in disrepair due to writings on the walls, broken plaster, and water problems. On the other hand, serious damage to the floors, walls, and ceiling inside the building is noticeable (Fig. 10). The wooden ceiling covering of this building has mostly collapsed, while the floor covering has also deteriorated and has collapsed in places. There is some material loss due to the removal of plaster on the walls and exposure to water, and especially large cracks at the joints. As a result of the current use of the building as a warehouse or animal shelter outside of its function, there is deterioration in the interior architecture in the form of neglect, dirt and ruins.

Fig. 10. Van Ernis Village Institute Dormitory Interior view

2.3. Van Ernis Village Institute Multi-Purpose Hall

The building has a rectangular plan in the east-west direction. Adjacent to the building is a rectangular plan building in the north-south direction in the southeast. The entrance to the building is provided by a rectangular plan door in the middle of the west facade (Fig. 11).

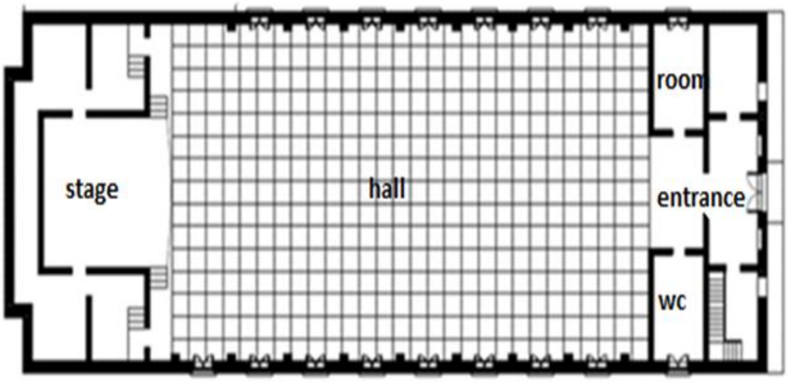

Fig. 11. Van Ernis Village Institute Multi-Purpose Hall plan

A hall was created after the entrance. There are one square-plan room in the north and south of the hall. Above these rooms, a slightly protruding area was created on the side facing the hall and a staircase was used to access this area from the room in the north. After passing through the hall, a second rectangular-plan hall was created and there are one rectangular-plan room in the north and south of this hall. The space in the north was used as a toilet. After the second hall, there is a large living room. There is a stage raised from the ground in front of the east wall of the building. The stage is accessed by a staircase with three steps from the north and south. There is a rehearsal room (backstage) on the north and south of the stage. These rooms can be accessed both from inside the hall and from the stage. There are nine window openings in the building, nine on the north facade, eight on the south facade and two on the entrance facade (Figs. 12-13). Regular cut stone was used as construction material on the walls of the building. The walls were plastered from the inside. The building was covered with a four-way inclined hipped roof covered with wood from the inside and metal sheet from the outside.

The Van Ernis Village Institute multipurpose hall was used for events such as cinema, theatre and concerts during the education period, and it is a very modern and functional structure for its time. However, this structure is also in a very worn-out state due to neglect and neglect due to not being used for many years. Although the integrity of the exterior has been preserved, especially the writings and paints on the doors and walls on the entrance facade, broken and damaged windows and doors, and also the bad appearances on the walls due to water and weather conditions are noticeable. However, the real damage in this structure is seen inside the structure. It is noteworthy that the ceiling coverings, which show the fine workmanship of the period it was built, have fallen off, the vertical plasters thought to be made for acoustic purposes on the walls have broken and material losses, large cracks and plaster removal at the wall, window and corner joints.

The area where Van Ernis Village Institute is located is in Muradiye district of Van province and is located in the 1st degree earthquake zone in the 2023 "Turkey Earthquake Zones Map" divided into 5 regions (URL-1, 2024). Van Province is one of the most important earthquake regions in Eastern Anatolia due to its location in the compression zone of the Eurasian and Arabian plates in terms of tectonics, at the intersection of the North Anatolian Fault Zone and the East Anatolian Fault Zone. The last two major earthquakes occurred in 2011.

Fig. 12. Van Ernis Village Institute Multi-Purpose Hall entrance facade

Fig. 13. Van Ernis Village Institute Multi-Purpose Hall entrance interior view

There are sandy, gravelly and clayey soil layers in Van, which is located on alluvial layers and is around the lake. Due to underground waters that approach the ground surface to a depth of 2 meters in some places, subsidence occurs in the foundations of some structures. Van Ernis Village Institute Campus is also in a 1st degree earthquake zone and all structures are located on such ground. It is thought that the cracks seen in the structures on the campus, especially in the dormitory and multipurpose hall, are after the earthquakes. Again, it is inevitable that there will be problems caused by ground water in the structures of the campus, which is surrounded by a lake on three sides. However, the greatest damage occurred because the structures were left alone for many years without being used or maintained. These empty structures were sometimes used as animal shelters or warehouses for nearby settlements, but in a rude manner, and it was observed that windows, doors, ceilings, walls and floor coverings were damaged by human hands. Damage and deterioration in structures increased due to climatic cycles, hot-cold temperature differences, precipitation, and also factors such as ground-based water, humidity and earthquakes.

3. Conclusions

Village institutes were one of the important elements that contributed to the development of both villages and cities and carried the society to the level of civilization. The Van Ernis Village Institute, which was opened last and unfortunately short-lived, includes a group of structures that made up the architectural heritage of the Republic, which contributed greatly to the environment it was located in despite its short life and still has a high symbolic value today. Some of the buildings made of stone of this institution are original structures that have survived from the Institute and maintain their façade integrity when viewed from the outside.

Within the scope of this study, three structures built of stacked stone located in a 1st degree earthquake zone and on alluvial ground were taken into consideration and the current status of the Van Ernis Village Institute structures was tried to be determined. Although there was no visible damage in the heating section of the bathhouse structure, which is the first of these structures and is even more important because it was built by the students themselves, it is noteworthy that damage formations started due to non-use, groundwater, rainfall and other environmental effects. Mass losses, abrasions and breaks are seen in the stones of the structure, which has not been used for a long time and has been abandoned to its fate. Lichens that have formed over time have started to damage the stones, especially in the dome. Due to the effects of water, humidity effects have also occurred in the walls and some other parts of the bath structure.

The greatest damage among the structures is seen in the dormitory building. Separation in the carrier system, material loss in the roof and walls, and abrasion in the floors constitute the main damages. Again, although there is no visible damage other than the pictures made outside the multipurpose hall, there are damages on the walls, floors and ceilings inside the structure due to long-term disuse. It is necessary to carry out studies to repair these damages, to prevent the structures from being damaged too much in the future and to protect them, and these processes should be continuous. The loss of properties and damages of the stone material used in the three structures considered over time due to natural processes may affect the load-bearing properties of the structures.

The stone structures on the Van Ernis Village Institute campus, like other buildings within the Institute, have preserved their authenticity since they were used until 2011. Today, it is seen that the settlement, which is completely idle, is prone to further destruction by people due to uncontrolled entries. Taking security measures within the campus and opening this area to use by assigning different functions is extremely beneficial in terms of both national wealth and national value. In particular, interventions to be made in the damages incurred in the Van Ernis Village Institute buildings, which are considered within the scope of the architectural heritage of the Republic period, in a way that preserves their authenticity and their use with the functions to be assigned will be important in terms of transferring these structures to the next generations.

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A review of applications of Monte Carlo Simulation in construction risk management

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Abstract. Effectively managing uncertainties and risks in construction projects is a critical factor influencing project success rates. Monte Carlo simulation, in particular, is a versatile method used in risk management to model possible scenarios and quantitatively predict their impacts on projects. This method enables project managers to understand potential risk effects better through hundreds or thousands of iterations and make informed decisions. Identifying, analyzing, and prioritizing risks is crucial in achieving project objectives related to cost, time, and quality. In this context, Monte Carlo simulation is a robust analytical tool that enhances risk management processes by enabling probabilistic analysis and scenario evaluation. This study provides an extensive literature review on applying Monte Carlo simulation to construction project risk management. Existing studies emphasize its contributions to risk analysis and prioritization, its capacity to measure uncertainties, and its transformative impact on project planning. The effectiveness of Monte Carlo simulation in generating probabilistic scenarios and evaluating their effects on project objectives has solidified its value in both theoretical and practical domains. The findings consolidate diverse perspectives from the literature, highlighting the pivotal role of Monte Carlo simulation in advancing risk management practices. This review is a comprehensive reference for understanding the method's practical benefits and theoretical foundations. It aims to encourage its broader adoption in construction risk management by addressing its advantages and potential challenges in various project scenarios.

Keywords: Monte Carlo Simulation; Risk Analysis; Risk Management; Construction Projects

1. Introduction

Construction projects are complex processes involving multiple stakeholders, variable parameters, and unpredictable conditions. The timely completion of projects, adherence to budget constraints, and achievement of desired quality standards are often influenced by multifaceted factors such as disruptions in material supply, fluctuating weather conditions, variations in labor productivity, and economic uncertainties (Chan et al., 2004). For instance, a sudden flood during bridge construction or an unexpected surge in steel prices in a skyscraper project can significantly jeopardize project objectives. Such uncertainties make the construction sector a high-risk domain, necessitating effective management of these risks. Unmanaged risks lead to financial losses, resulting in broader consequences such as reputational damage and operational disruptions (Akintoye & Macleod, 1997).

In this context, risk management emerges as a fundamental discipline that directly impacts the success of construction projects. The systematic identification, analysis, and prioritization of risks enables project managers to anticipate potential threats and develop proactive solutions (Iqbal et al., 2015). For example, the early detection of ground subsidence risk in a tunnel project allows for the design of appropriate support systems, providing significant advantages in terms of safety and cost efficiency. However, when risk management processes are neglected, even a minor disruption can trigger a domino effect, leading to delays, budget overruns, and, in extreme cases, complete project failure. Consequently, risk analysis has become an integral part of modern project planning and is recognized as an indispensable element for achieving sustainable success in the construction industry (Khodabakhshian et al., 2023).

Monte Carlo simulation is a powerful tool for quantitatively modeling risks and uncertainties (Arunraj et al., 2023). By employing random variables to simulate hundreds or even thousands of possible scenarios, this method goes beyond traditional deterministic approaches by providing a probabilistic distribution of project outcomes. While deterministic methods typically focus on a single "most likely" scenario, Monte Carlo simulation reflects

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real-world complexity by assessing the interactions of variables and the cumulative effects of risks (Bouayed, 2016).

This paper aims to review the applications of Monte Carlo simulation in the construction risk management process. By exploring the theoretical foundations and practical benefits of the method, it seeks to enhance the effectiveness and data-driven nature of risk management in the construction sector. This review study focuses on how Monte Carlo simulation can be utilized across a wide range of applications, from cost estimation to time scheduling, while addressing the challenges that may limit its applicability and strategies for overcoming these challenges. In this regard, the paper aspires to serve as a comprehensive guide for academics and industry professionals, encouraging the broader adoption of the method in construction risk management.

1.1. Concept of Risk

Risk can be defined as events or conditions that emerge under uncertainty and have the potential to positively or negatively impact a project's objectives. In the project management literature, risk often focuses on adverse outcomes; however, risks can also present opportunities. Nonetheless, risks are typically perceived as threats that may hinder the achievement of project goals (Aven, 2017).

Risk consists of two key components:

- Probability: The likelihood of a risk occurring.
- Impact: The risk's consequences on the project if it occurs.

These two components determine the severity of the risk. For instance, high-probability and high-impact risks present the greatest threats to a project, while low-probability and low-impact risks are less significant (Duijm, 2015).

1.2. Risk Management

Risk management is a systematic process aimed at identifying, analyzing, and developing strategies to address risks that may arise during project processes, ultimately ensuring the achievement of project objectives (Thamhain, 2013). Risk management originated in the insurance industry in the early 20th century and has since been applied in various fields, including project management, finance, and engineering. Particularly after the 1980s, risk management processes became standardized within project management (Smith & Merritt, 2002). Risk management plays a critical role in project success because, as the complexity and uncertainty of projects increase, the impact of risks also escalates (Taroun, 2014).

Risk management is critical in complex and large-scale projects (Qazi & Dikmen, 2019). Construction projects inherently involve high uncertainty and risk. These risks can lead to delays, cost overruns, or a decline in quality. Risk management offers a proactive approach to prevent or minimize such adverse outcomes (Akintoye & Macleod, 1997).

In particular, risk management becomes even more critical in sustainability-focused projects (e.g., energy-efficient building projects). These projects typically involve more significant uncertainty and complexity than traditional projects (Nawaz et al., 2019). For instance, the availability of green materials, challenges in achieving energy efficiency goals, or problems from implementing new technologies can increase project risks.

PMBOK (2018) addresses risk management under seven core processes. These processes follow the Plan, Define, Analyze, Respond, and Monitor/Control framework.

- *Risk Identification*: Risk identification involves identifying all potential risks that may arise during the project lifecycle. In this step, the project team, stakeholders, and experts provide their insights to identify project-specific risks more comprehensively. Stakeholders can anticipate risks at different project stages and assess their potential impacts (Hillson, 2002). The risk identification process uses brainstorming, expert opinions, historical project data, and risk checklists (Thamhain, 2013).
- *Risk Analysis*: Risk analysis assesses the likelihood and impact of identified risks. In this step, the potential effects of risks on the project are analyzed either quantitatively or qualitatively. Quantitative analysis involves numerically evaluating risks, while qualitative analysis involves classifying risks based on their relative importance (Ward & Chapman, 1991).
- *Risk Prioritization:* Risk prioritization involves ranking risks based on their potential impact on the project. This step creates a risk matrix using the likelihood and impact values of risks. The risk matrix allows for classifying risks as high, medium, or low priority (Dandage et al., 2019).
- *Risk Response Planning*: Risk response planning involves developing strategies to reduce or eliminate the effects of risks. This step defines risk prevention, mitigation, transfer, or acceptance strategies. For example, additional measures may be taken for a high-risk situation, or the risk can be transferred through insurance (Zhang, 2016).
- *Risk Monitoring and Control*: Risk monitoring and control is tracking risks throughout the project and taking necessary actions. In this step, the status of risks is regularly reviewed, and as new risks emerge, the risk management process is updated (Levene & Lewis, 2015).

1.3. Monte Carlo Simulation

Monte Carlo simulation is a statistical technique that employs random sampling to model and analyze complex systems affected by uncertainty, making it a vital tool for construction risk management. By generating thousands of possible scenarios, it quantifies the impacts of risks on project objectives such as cost, schedule, and quality, surpassing the limitations of deterministic methods (Labeau & Zio, 2002; Peleskei et al., 2015).

Grounded in probability theory, Monte Carlo simulation leverages principles like the law of large numbers and the central limit theorem to represent a system's potential states through random sampling. It addresses high-dimensional computations, optimization challenges, and stochastic processes, particularly when deterministic approaches are impractical or computationally intensive. In construction, it enables project managers to assess risks arising from material price volatility or schedule delays by modeling variable interactions (Cheng & Guo, 2024; Rubinstein, 1981).

The simulation process follows a structured sequence. Initially, the system, such as a construction project's cost or schedule, is defined, along with desired outputs. Probability distributions for input variables (e.g., labor productivity, material costs) are established using historical data, expert opinions, or theoretical models. Random samples are then generated from these distributions using random number generators, and the system is modeled for each sample set to produce outputs. Finally, results are statistically analyzed using metrics like mean, variance, and confidence intervals to evaluate uncertainty impacts, often supplemented by sensitivity analysis to identify critical inputs (Paxton et al., 2001; Wei et al., 2013).

The accuracy of the Monte Carlo simulation hinges on several factors. A sufficient number of iterations—typically thousands—ensures statistically reliable results, improving accuracy as sample size increases. The model's fidelity to the real system, validated through experimental data or analytical solutions, is crucial. Additionally, the quality of random number generators influences outcome reliability. In construction, inaccurate input data, such as incomplete cost records, can undermine results, necessitating robust data collection (Ramírez-Márquez & Coit, 2005; Kwak & Ingall, 2007).

Simulation outputs should be calibrated against real-world data to enhance result validity, with model parameters adjusted as needed. Conducting scenario and sensitivity analyses further tests the model's performance across diverse conditions, ensuring its applicability to complex construction projects. These steps are critical for mitigating risks in large-scale infrastructure or sustainable construction initiatives (Khodabakhshian et al., 2023).

Monte Carlo simulation is a cornerstone of modern risk management, with origins in nuclear physics and widespread applications in finance, engineering, and construction. Providing probabilistic insights into uncertainties empowers project managers to make informed decisions, develop proactive risk mitigation strategies, and optimize resource allocation, thereby enhancing project success in the dynamic construction industry (Brandimarte, 2014; Peleskei et al., 2015).

2. Research Methodology

This study adopts a literature review methodology to examine the use of Monte Carlo Simulation in construction risk management. This review aims to synthesize findings from existing academic sources to understand how Monte Carlo Simulation has been applied in various contexts within the construction sector. Specifically, the study explores the methodological contributions of Monte Carlo Simulation to risk analysis, highlights the advantages and limitations associated with its use, and identifies the industry-specific domains where it has been most effectively implemented, such as cost estimation, schedule forecasting, and resource planning.

3. Results and Discussion

Table 1 presents the literature review results. These results reveal the Monte Carlo Simulation's capacity to model uncertainties, conduct probabilistic risk analyses, and predict the effects of risks on project objectives. This section synthesizes the key results from the literature review and discusses the significance of these findings in construction risk management.

Monte Carlo simulation is commonly employed in the construction sector, where project management and cost estimation are processes characterized by high uncertainty. Ildarabadi et al. (2021) demonstrated that using a Monte Carlo simulation for financial risk assessment in construction projects made cost estimates more reliable. Similarly, Sadeghi et al. (2010) developed a more flexible analytical method by combining fuzzy logic with Monte Carlo simulation for risk analysis in the construction sector. Qazi et al. (2021) examined the effectiveness of Monte Carlo simulation in risk prioritization for sustainable construction projects and showed that it scientifically grounded the ranking of risk factors. Another study by Peleskei et al. (2015) explored how Monte Carlo simulation could improve the accuracy of cost estimates in construction projects.

Table 1. Monte Carlo Simulation Applications for Construction Risk Management in the literature

Source	Title	Scope	Problem	Topic	Method	Objective	Findings
Wall (1997)	***"Distributions and Correlations in Monte Carlo Simulation"***	Cost modeling in construction projects	Neglecting correlations between variables in Monte Carlo simulations	Correlation analysis in Monte Carlo simulations	Statistical Distributions, Monte Carlo Simulation, Correlation Analysis	To analyze correlations between variables in Monte Carlo simulations	Ignoring correlations can lead to flawed risk analyses, so correlations should be analyzed.
Bonate & P.L. (2001)	*"A Brief Introduction to Monte Carlo Simulation"*	Basic principles and applications of Monte Carlo simulation	Managing uncertainties in modeling random processes	Definition and application areas of Monte Carlo simulation	Statistical Analysis, Probability Distributions, Random Sampling	To introduce the fundamental mechanism of Monte Carlo simulation	Monte Carlo simulation is a powerful tool for analyzing complex systems.
Yeung (2001)	***"The Role of Monte Carlo Simulation in Risk Analysis of Large Infrastructure Projects"***	Risk analysis in large-scale infrastructure projects	Uncertainties in cost and time estimates for infrastructure projects	Risk management in large projects using Monte Carlo simulation	Monte Carlo Simulation, Risk Analysis Models	To improve risk analysis in large infrastructure projects	Monte Carlo simulation helps better manage uncertainties in infrastructure projects.
Papadopoulos & Yeung (2001)	***"Uncertainty Estimation and Monte Carlo Simulation Method"***	Uncertainty estimation and Monte Carlo simulation	How to handle uncertainties in complex systems	Uncertainty modeling with Monte Carlo simulation	Monte Carlo Simulation, Statistical Uncertainty Analysis	To demonstrate the usability of Monte Carlo methods in uncertainty estimation	Monte Carlo simulation is a powerful method for modeling uncertainty.
Kwak & Ingall (2007)	***"Exploring Monte Carlo Simulation Applications for Project Management"***	Use of Monte Carlo simulation in project management	Ineffective management of uncertainties in project schedules	Project risk analysis with Monte Carlo simulation	Monte Carlo Simulation, Project Management Models	To show the applicability of Monte Carlo simulation in project management	Monte Carlo simulation helps make project schedules more reliable.
Rezaie et al. (2007)	***"Using Extended Monte Carlo Simulation Method for the Improvement of Risk Management: Consideration of Relationships Between Uncertainties"***	Project and risk management processes	Monte Carlo method's failure to account for relationships between uncertainties and shortcomings in decision support processes	Monte Carlo simulation in risk management	Extended Monte Carlo Simulation, Cyclic Algorithm	To improve the Monte Carlo method and risk management by considering relationships between uncertainties	The cyclic algorithm better models' interactions between uncertainties, increasing the accuracy of classic Monte Carlo simulation.
Raychaudhuri (2008)	***"Introduction to Monte Carlo Simulation"***	General introduction to Monte Carlo simulation	Inability to predict processes involving uncertainty	Monte Carlo simulation and its application areas	Statistical Analysis, Random Number Generation, Probability Distributions	To explain the basic principles of Monte Carlo simulation	Monte Carlo simulation is a powerful analysis method with a wide range of applications.
Silver & Tesauro (2009)	***"Monte Carlo Simulation Balancing"***	Balancing techniques in Monte Carlo simulations	Uneven distribution and errors in Monte Carlo simulations	Monte Carlo simulation optimization	Machine Learning, Monte Carlo Simulation, Game Theory	To make Monte Carlo simulations more balanced and efficient	Improved balancing algorithms increase the reliability of simulation results.
Wang & Huang (2009)	***"Risk Analysis of Construction Schedule Based on Monte Carlo Simulation"***	Time management in construction projects	Uncertainties in construction project scheduling causing delays	Time risk analysis in construction projects	Monte Carlo Simulation, Critical Path Method (CPM), Beta Distribution	To estimate completion time and optimize risk management in construction projects	Monte Carlo simulation makes scheduling more reliable by analyzing specific delay scenarios.

Table 1 continued

Harrison & R.L. (2010)	***"Introduction to Monte Carlo Simulation"***	History and basic principles of Monte Carlo methods	Inadequacy of analytical methods for complex systems	The role of Monte Carlo simulation in scientific research	Random Number Generation, Probability Distributions, Simulation Analysis	To explain the use of Monte Carlo methods in various scientific fields	Monte Carlo simulation has a wide range of applications and is highly versatile.
Sadeghi et al. (2010)	***"Fuzzy Monte Carlo Simulation and Risk Assessment in Construction"***	Fuzzy logic and Monte Carlo methods in construction projects	Modeling and assessing uncertainties in construction projects	Integration of fuzzy logic and Monte Carlo simulation	Fuzzy Logic, Monte Carlo Simulation, Risk Analysis	To improve risk assessment methods in the construction industry	Fuzzy Monte Carlo Simulation enables more effective risk management with uncertain data.
Gimpelevich (2011)	***"Simulation-Based Excess Return Model for Real Estate Development"***	Real estate development projects	Shortcomings of the Discounted Cash Flow (DCF) model and lack of probabilistic analysis	Risk management in real estate investment projects	Monte Carlo Simulation, Stochastic Modeling, DCF Analysis	To develop a new model for better analyzing risks and probabilistic outcomes in real estate projects	The Simulation-Based Excess Return Model (SERM) provides more accurate predictions than traditional DCF analysis.
Loizou & French (2012)	***"Risk and Uncertainty in Development Using Monte Carlo Simulation"***	Real estate development projects	Monte Carlo simulation overlooking human factors	Risk management and uncertainty analysis with Monte Carlo simulation	Monte Carlo Simulation, Decision Theory, Sensitivity Analysis	To evaluate the effectiveness of Monte Carlo simulation in real estate development projects	Monte Carlo simulation offers more reliable risk predictions when combined with human factors.
Jato-Espino et al. (2014)	***"A Review of Application of Multi-Criteria Decision-Making Methods in Construction"***	Multi-criteria decision-making methods in construction projects	Determining optimal decisions among multiple criteria in construction projects	Project management with Monte Carlo and other MCDM methods	Monte Carlo Simulation, AHP, TOPSIS, MCDM	To improve decision-making processes in construction projects	Monte Carlo simulation is an effective method in multi-criteria decision analysis.
Kong et al. (2015)	***"Plan Schedule Risk Assessment Using Monte Carlo Simulation"***	Plan management in construction projects	Traditional planning methods ignoring uncertainties	Time management and risk analysis in construction projects	Monte Carlo Simulation, Critical Path Method (CPM), Probabilistic Distribution	To identify and mitigate time management risks in construction projects	Monte Carlo simulation enables more reliable project plans by accounting for uncertainties.
Smith et al. (2015)	***"Exploring Risk Management Techniques in Construction Using Monte Carlo Simulation"***	Risk management in construction projects	Insufficient modeling of risks in the construction industry	Risk assessment with Monte Carlo simulation	Monte Carlo Simulation, Risk Assessment Techniques	To improve risk management in construction projects	Monte Carlo simulation is an effective tool for risk management in construction projects.
Baumgertel et al. (2016)	***"Risk Assessment in Flood Defense Project Using Monte Carlo Simulation"***	Flood control projects	Cost uncertainties and risk management deficiencies in flood control projects	Risk management in flood defense projects	Monte Carlo Simulation, Risk Analysis, Financial Reserve Estimation	To manage risks and unexpected costs in flood control projects	Monte Carlo simulation reduces cost uncertainties, enabling better reserve planning.
Abdelmageid (2017)	***"Application of Risk Management and Monte Carlo Simulation on a Construction Project"***	Risk estimation in construction projects	Insufficient evaluation of uncertainties and risks affecting project success	Risk analysis in construction projects	Monte Carlo Simulation, Sensitivity Analysis, Risk Management	To better manage risks and prevent potential delays in construction projects	Analyses with Monte Carlo simulation make project planning more reliable.

Table 1 continued

Allahi et al. (2017)	***“Stochastic Risk Analysis and Cost Contingency Allocation Approach for Construction Projects”***	Cost estimation in construction projects	Unexpected costs causing budget overruns in construction projects	Cost management in construction projects	Monte Carlo Simulation, Stochastic Modeling, Probabilistic Distribution	To manage budget uncertainties in construction projects	Monte Carlo simulation reduces budget uncertainties, enabling more realistic cost estimates.
Tong et al. (2018)	***“The Construction Dust-Induced Occupational Health Risk Using Monte Carlo Simulation”***	Occupational health and safety in the construction industry	Uncertainty regarding the health impacts of dust pollution in construction sites	Construction dust-induced occupational health risks	Monte Carlo Simulation, Probabilistic Risk Assessment	To determine the risk of construction dust exposure for workers and assess its health impacts	Monte Carlo analysis reveals that workers in certain areas face higher health risks.
Anderson & Kim (2019)	***“Optimizing Decision Making with Monte Carlo Simulation”***	Monte Carlo simulation in decision-making processes	Ineffective management of uncertainties in complex decision processes	Decision analysis with Monte Carlo simulation	Monte Carlo Simulation, Decision Support Systems	To demonstrate how Monte Carlo simulation can support decision-making processes	Monte Carlo simulation provides reliable analysis in uncertain decision processes.
Rausch et al. (2019)	***“Monte Carlo Simulation for Tolerance Analysis in Prefabrication and Offsite Construction”***	Prefabrication and offsite construction processes	Tolerance accumulation, dimensional mismatches, and rework costs in prefabricated components	Tolerance analysis in prefabrication and offsite construction	Monte Carlo Simulation, 3D CAD Modeling, Tolerance Chain Analysis	To analyze and optimize tolerance management and rework risks due to dimensional variability in prefabrication	Monte Carlo method effectively predicts tolerance accumulation and optimizes construction processes, reducing rework risk by 65.6%.
Wali & Othman (2019)	***“Schedule Risk Analysis for Residential Projects Using Monte Carlo Simulation”***	Time management in residential projects	Failure to complete residential projects on schedule	Time risk analysis in residential projects	Monte Carlo Simulation, Critical Path Method (CPM), PERT	To optimize scheduling in residential projects	Monte Carlo simulation can estimate project duration based on specific risk levels.
García et al. (2020)	***“Monte Carlo Methods for Predictive Analytics”***	Monte Carlo methods in predictive analytics	Need to increase the accuracy of predictive models	Data analysis with Monte Carlo simulation	Monte Carlo Simulation, Big Data Analytics	To show the use of Monte Carlo methods in predictive analytics	Monte Carlo simulation can help improve the accuracy of predictive models.
Peleskei et al. (2015)	***“Risk Consideration and Cost Estimation in Construction Projects Using Monte Carlo Simulation”***	Cost estimation in construction projects	Ignoring uncertainties in cost estimates for construction projects	Cost risk management in construction projects	Monte Carlo Simulation, Probabilistic Distribution Analysis	To better estimate cost risks in construction projects	Monte Carlo simulation makes cost estimates more reliable, minimizing risks.
Sharma (2020)	***“Monte Carlo Simulation Applications for Construction Project Management”***	Risk management in construction projects	Inadequate implementation of risk management processes in construction projects	Risk management in construction projects	Monte Carlo Simulation, Risk Management Processes	To make risk management more effective in construction projects	Integrating Monte Carlo simulation into risk management processes significantly improves project success.

Table 1 continued

Ildarabadi et al. (2021)	*"Proposing a New Function for Evaluation of the Financial Risk of Construction Projects Using Monte Carlo Method"*	**Monte Carlo simulation for financial risk analysis in construction projects**	**Uncertainties in cost estimates for construction projects**	**Financial risk management with the Monte Carlo method**	**Monte Carlo Simulation, Risk Analysis, Financial Modeling**	**To evaluate financial uncertainties in construction projects**	**Monte Carlo simulation can improve risk management in construction projects.**
Koulinas et al. (2021)	***"A TOPSIS—Risk Matrix and Monte Carlo Expert System for Risk Assessment in Engineering Projects"***	Risk assessment methods in engineering projects	Incorrect evaluation of risk factors in projects	Monte Carlo simulation and risk matrices	TOPSIS, Monte Carlo Simulation, Risk Analysis	To increase the accuracy of risk assessment in projects	Monte Carlo simulation is an effective support tool in risk analysis.
Qazi et al. (2021)	***"Prioritizing Risks in Sustainable Construction Projects Using a Risk Matrix-Based Monte Carlo Simulation Approach"***	Risk prioritization in sustainable construction projects	Inadequate classification of risk factors in construction projects	Improving risk analysis with Monte Carlo simulation	Monte Carlo Simulation, Risk Matrices	To make risk management more effective in the construction industry	The combination of risk matrices and Monte Carlo simulation improves decision-making in sustainable projects.
Sobieraj & Metelski (2022)	***"Project Risk in Construction Schedules Using Monte Carlo Simulation"***	Large-scale construction projects	Complexity of time management in large-scale construction projects	Time and risk analysis in construction projects	Monte Carlo Simulation, Time at Risk (TaR) Approach	To manage schedule overrun risks in construction projects	Monte Carlo simulation improves scheduling by modeling risks at different stages.
Martinez et al. (2022)	***"Risk Assessment in Renewable Energy Projects Using Monte Carlo Simulation"***	Risk analysis in renewable energy projects	Cost and production uncertainties in renewable energy projects	Risk management in energy projects with Monte Carlo simulation	Monte Carlo Simulation, Energy Production Risk Models	To improve risk management in renewable energy projects	Monte Carlo simulation enables better management of renewable energy projects.
Peleskei et al. (2025)	***"Risk Consideration and Cost Estimation in Construction Projects Using Monte Carlo Simulation"***	Risk analysis and cost estimation in construction projects	Low accuracy of cost estimates in construction projects	Construction cost management with Monte Carlo simulation	Monte Carlo Simulation, Financial Modeling	To improve risk-based cost estimates in construction projects	Monte Carlo simulation can increase the accuracy of cost analysis in construction projects.

As seen in Table 1, the literature review shows that Monte Carlo simulation is widely used in various areas of construction risk management, such as cost estimation, scheduling, and contingency planning. For instance, Peleskei et al. (2015) and Allahi et al. (2017) demonstrated that the method significantly enhances the accuracy of cost estimates by accounting for uncertainties such as material price fluctuations, labor efficiency, and unforeseen events. Similarly, Wang and Huang (2009) and Wali and Othman (2019) showed that Monte Carlo simulation, when combined with techniques like the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT), improves the reliability of project completion time predictions. These findings validate the method's ability to overcome the limitations of deterministic approaches and provide probabilistic result ranges that better reflect the complex and variable nature of construction projects.

The role of simulation in risk prioritization is another important finding that contributes to the improvement of resource allocation and strategic planning. Baumgertel et al. (2016) used the method in flood defense projects to identify critical cost risks and ensure more accurate contingency reserves. Similarly, Tong et al. (2018) applied a Monte Carlo simulation to evaluate occupational health risks caused by construction dust, revealing higher exposure risks in certain site areas and facilitating the implementation of targeted mitigation measures. These applications showcase the method's versatility in addressing financial and non-financial risks and provide project managers with actionable insights for reducing significant uncertainties. Probabilistic outputs such as histograms or cumulative distribution functions present the likelihood and magnitude of risks in an accessible manner, facilitating decision-making processes.

The integration of Monte Carlo simulation with complementary techniques enhances its effectiveness. Sadeghi et al. (2010) combined fuzzy logic with Monte Carlo simulation to obtain more robust cost risk assessments with incomplete or uncertain data. Similarly, Rezaie et al. (2007) introduced a cyclical algorithm to model interdependencies among uncertainties, improving the method's accuracy compared to traditional Monte Carlo approaches. These developments demonstrate that the natural limitations of Monte Carlo simulation, such as neglecting inter-variable dependencies highlighted by Wall (1997), can be overcome through hybrid methodologies. These findings emphasize the importance of adapting the method according to specific project contexts and data suitability.

However, applying a Monte Carlo simulation in construction risk management faces some challenges. The accuracy of simulation results heavily depends on the quality of input data and the appropriateness of the selected probability distributions. Studies like Kwak and Ingall (2007) warn that poorly defined inputs or insufficient sample sizes can jeopardize the reliability of results. Additionally, the computational complexity of the method and the need for specialized software such as @Risk or Crystal Ball can pose obstacles, particularly in small-scale projects or teams with limited technical expertise (Taylor & Brown, 2021). These limitations indicate that while Monte Carlo simulation has transformative potential, successful application requires robust data collection processes and skilled personnel.

The discussion of these findings highlights the transformative impact of Monte Carlo simulation in construction risk management. Providing a probabilistic framework allows project managers to move beyond point estimates and fosters a more proactive and informed approach to risk mitigation. This aligns with a broader shift toward data-driven decision-making in the construction industry, as evidenced by its increasing adoption in large-scale infrastructure projects (Yeung, 2001) and sustainable construction initiatives (Qazi et al., 2021). However, the identified challenges suggest that the method requires ongoing refinement. Improving data quality through historical project records, integrating artificial intelligence for real-time uncertainty modeling, and developing user-friendly tools could overcome these barriers and make the method more accessible across different project scales.

Monte Carlo simulation is a crucial tool in advancing construction risk management by providing a detailed understanding of uncertainties and their impacts. Its ability to generate reliable cost and time estimates, prioritize risks, and support contingency planning is a cornerstone of modern project management practices. However, maximizing its benefits depends on addressing implementation challenges through education, data management, and technological innovation. These findings reinforce the method's theoretical and practical value and pave the way for future research to optimize its application in the evolving landscape of construction projects.

Monte Carlo simulation offers a range of advantages and some limitations. According to Raychaudhuri (2008), this method excels at handling uncertainty by incorporating random variables into the modeling process. Bonate (2001) highlights its versatility across various application areas, while Kwak and Ingall (2007) emphasize its effectiveness in generating accurate forecasts within decision support systems. Recent studies further underscore its strengths in construction risk management. For instance, Khodabakhshian et al. (2023) note that Monte Carlo simulation enhances decision-making by providing probabilistic outputs that account for complex interdependencies among project variables, such as material costs and labor productivity, thus enabling more robust contingency planning. Additionally, Martinez et al. (2022) demonstrate its value in renewable energy construction projects, where it facilitates precise risk assessments by modeling uncertainties in energy production and cost estimates, contributing to sustainable project outcomes.

On the other hand, Harrison (2010) notes that the method can be computationally intensive, particularly in large-scale implementations. Silver and Tesauro (2009) argue that the accuracy of the simulation heavily relies on the quality and appropriateness of the probability distributions used for input variables. Recent literature reinforces these limitations and identifies new challenges. For example, Taylor and Brown (2023) highlight that integrating Monte Carlo simulation with emerging technologies, such as artificial intelligence, can increase computational demands, requiring advanced hardware and skilled personnel, which may be prohibitive for smaller construction firms. Furthermore, Peleskei et al. (2015) point out that inconsistencies in historical data, often due to incomplete project records in developing regions, can undermine the reliability of simulation results, necessitating rigorous data validation processes. Despite these challenges, advancements in cloud-based simulation platforms and automated data preprocessing, as discussed by Cheng and Guo (2024), are beginning to mitigate computational and data-related barriers, making the method more accessible across diverse project scales.

4. Conclusion and Recommendations

This study has investigated the use of Monte Carlo simulation in the risk management processes of construction projects, emphasizing its role in modeling uncertainties, evaluating risks, and ensuring alignment with project goals. Based on the literature review, methodological analysis, and discussion of findings, it is evident that the Monte Carlo simulation serves as a valuable and practical tool within the construction industry. The study's key findings confirm the method’s ability to improve the reliability of cost and time estimates, prioritize risks, and frame decision-making processes within a data-driven context.

The main results show that the method goes beyond deterministic approaches, providing probabilistic scenarios that allow project managers to understand the complex nature of uncertainties better. Additionally, integrating complementary techniques (e.g., fuzzy logic or cyclic algorithms) has enhanced the accuracy of analyses, further strengthening the method's practical value. However, challenges such as data quality, technical expertise requirements, and software dependencies were identified as limiting factors in the method's applicability.

Monte Carlo simulation fosters a proactive approach to construction risk management, addressing the shortcomings of traditional methods. Forecasting the range of potential values for project duration or cost with a certain probability provides managers with a solid foundation for developing risk mitigation strategies and optimizing resource allocation. Especially in large-scale and complex projects, the advantages offered by this method can potentially increase project success. However, fully realizing this potential depends on improvements in data collection processes, staff training, and the development of user-friendly technologies.

The results of this study lay the groundwork for encouraging broader adoption of Monte Carlo simulation in construction risk management. By systematically addressing uncertainties, the method increases the likelihood of achieving project objectives in terms of time, cost, and quality. However, several recommendations can be made to maximize the method's effectiveness. First, construction companies should systematically archive historical project data and incorporate it into simulation models to improve the quality of input data. Second, sector-specific training programs should be developed to enhance the competence of project teams in applying Monte Carlo simulation. Third, integrating innovative technologies such as artificial intelligence and machine learning with the simulation could enhance accessibility and accuracy by enabling real-time risk analysis and faster computation. Lastly, developing low-cost and user-friendly software tools should be encouraged to facilitate the method's adoption.

Future research presents significant opportunities to implement these recommendations and further enhance the application of Monte Carlo simulation in the construction industry. For example, creating risk models specific to different project types (e.g., infrastructure, residential, industrial facilities) could broaden the method's sectoral applicability. Additionally, studying the impact of simulation on sustainability-focused projects could provide new insights into how eco-friendly construction practices can be supported through effective risk management. Such research could strengthen the theoretical foundations of Monte Carlo simulation while making its practical application more accessible and effective.

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A roadmap for preliminary assessment of energy performance in traditional houses: The case of Ayvalık

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Abstract. Ayvalık traditional houses, located in the province of Balıkesir, Turkey, represent the rich cultural and architectural heritage of the region. The conservation of these houses includes not only preserving their architectural and environmental features but also ensuring the continuity of life within them. In this context, maintaining thermal comfort conditions for users is essential. This study aims to carry out a preliminary assessment of Ayvalık traditional houses in terms of energy performance and to propose a roadmap for energy-oriented research in historic settlements. The assessment, developed through on-site investigations, involves the systematic collection and organization of data. The study also intends to serve as a foundation for future research on the energy performance of traditional houses. Within this scope, a preliminary assessment was carried out on six traditional houses located in the traditional urban pattern of Ayvalık through on-site investigation and documentation, focusing on their architectural characteristics and environmental context. Subsequently, the strengths and weaknesses of the houses were analyzed both quantitatively and qualitatively in terms of climate and energy performance. The study demonstrates that it is possible to assess the energy performance of traditional houses while preserving their historical value. Based on the results, it can also be stated that energy performance assessments should be integrated with conservation practices to ensure sustainability in traditional houses. Accordingly, a roadmap has been developed to guide future energy-oriented studies on traditional houses, while respecting their historical values.

Keywords: Ayvalık; Traditional Houses; Energy Performance; On-site Investigation

1. Introduction

Traditional houses represent significant heritage assets with their architectural features, as well as their socio-cultural, economic, and environmental sustainability values. They are the products of local construction techniques that have been shaped by the climatic conditions, natural resources, and social lifestyles of their geographic context (Kuban, 1995). In this regard, traditional houses should be considered as dynamic resources that not only embody the aesthetic and historical heritage of the past but also transmit knowledge of sustainable building culture to the present. The preservation and continued use of these houses are essential for safeguarding cultural continuity. Today, conservation approaches have taken on a multidimensional character, focusing on both the preservation of the original form of the structures and the maintenance of their usability through adaptation to contemporary needs (ICOMOS, 2021; Onecha et al., 2021). In this context, integrating sustainability principles into the conservation of cultural heritage buildings has become increasingly important. Assessing traditional houses in terms of both their cultural significance and environmental performance provides a contemporary perspective for sustainable conservation practices.

Today, global challenges such as increasing energy consumption, climate change, and environmental sustainability have made it necessary to re-evaluate building performance through a performance-oriented approach. This has brought renewed attention to the potential of traditional houses in terms of energy efficiency (Eres & Güler, 2022). The use of local materials, thick stone walls, shading elements such as overhanging structures, narrow street layouts, and spatial configurations that promote natural ventilation all reveal that traditional houses were designed based on passive climate control strategies. In this context, assessing the energy performance of traditional houses is essential both to align conservation strategies with contemporary environmental goals and to ensure the sustainable adaptation of the existing building stock (Gou et al., 2015; Özbalta et al., 2021; Kaoua et al., 2022).

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Numerous studies have been conducted at both national and international levels on the energy performance of traditional houses. Different climatic conditions, geographical features, and cultural lifestyles have been fundamental factors shaping the design of these structures. This diversity has enabled the development of passive design strategies aimed at enhancing energy efficiency. For instance, studies on “Machiya” traditional houses in Japan have shown that these houses adapted to high humidity and seasonal temperature variations, enhancing indoor comfort through sliding panels that promote natural ventilation and shading (Iba & Hokoi, 2022). Similarly, “Hanok” traditional houses in Korea emphasize energy efficiency through ondol, a floor heating system that minimizes heat loss in winter, and wide eaves that provide cooling in summer (Lee et al., 2020). In Nepal, material choices vary according to climatic zones: stone and adobe with high thermal mass are preferred in colder regions, while lightweight timber walls are more common in subtropical areas (Gautam et al., 2019). In Spain, particularly in the Andalusia region, courtyard-integrated house plans are widely used, creating a cooling effect by facilitating natural ventilation within indoor spaces (Torres-González, 2025). As in other countries, studies on traditional house typologies across different climatic zones in Turkey have quantitatively demonstrated the adaptive capacity of these structures to local environmental conditions. For instance, research on Safranbolu traditional houses revealed that indoor temperatures remain more stable compared to outdoor conditions during both the hottest and coldest days of the year, achieving a certain level of thermal comfort without the use of active heating or cooling systems (Ulukavak Harputlugil & Çetintürk, 2005). Likewise, measurements conducted on the traditional timber-framed "Düğmeli" houses in the İbradı-Ormana region of Antalya showed that, while outdoor temperatures exceeded 35°C during the hottest summer days, the interior temperatures of stone-walled houses remained consistently between 27–29°C throughout the day (Tüfekçi Topkaya, 2022). A comparative study between the traditional “Mungan” house and the modern “Demir” house in Mardin further revealed that the Mungan house, with its thick stone walls, maintained indoor temperatures 4–5°C lower and more stable than those of the modern house (Manioğlu & Yılmaz, 2008).

The literature highlights the necessity of on-site investigation in understanding the energy performance of traditional houses. In this context, the *Preliminary Assessment of Energy Performance in Traditional Houses* method developed in this study was applied to Ayvalık. The research involves a systematic process of data collection and organization at the settlement, building, and building component scales. In the initial stage of on-site investigation and documentation, the historical and cultural background of the examined settlement was studied. In subsequent stages, evaluations related to the energy performance of the traditional houses were conducted, ranging from the settlement scale to the material scale. The outcomes of this study are expected to provide a roadmap for future energy-oriented research on traditional houses.

2. The architectural and cultural significance of Ayvalık traditional houses

Ayvalık is a distinctive settlement both for its natural landscapes and its traditional houses, which have developed through a long historical process and have significant architectural and cultural value. The traditional settlement pattern, particularly concentrated in the town center, holds a special position in terms of the conservation of cultural heritage. The first official step toward protecting the settlement was taken in 1976, when the High Council of Immovable Antiquities and Monuments designated Ayvalık as a "site area to be preserved as a whole with its natural and historical assets" under decision number A-160 (Erdem et al., 2007). Following this designation, conservation plans and registration efforts were implemented, and today two separate urban conservation areas have been defined, covering Ayvalık and Alibey (Cunda) Island. Fig. 1 illustrates the boundaries of urban conservation and natural protected areas designated with varying protection levels, together with a satellite image that shows the general morphology of the settlement.

The traditional houses within the urban conservation area, with their architectural diversity, offer insights into the historical transformations of the settlement. Despite changing user needs and spatial demands over time, many buildings have preserved their original identity, although in some cases, traditional spatial arrangements have been replaced by new functional interventions. This transformation has shaped both the historical and structural development of the settlement, influencing the architectural and cultural values of Ayvalık. In this context, the historical and structural development of the traditional settlement pattern is addressed under separate subheadings.

2.1. Historical Development

Ayvalık, located in the Balıkesir province, is a coastal settlement on the northern shore of the Aegean Sea, historically distinguished by its economic activities and geographical characteristics. The spatial and cultural development of the town was shaped by a rural economy based on olive production, the conditions of the natural environment, and its multi-layered social structure. Under these influences, Ayvalık evolved into an important Greek settlement under Ottoman rule starting from the 17th century. In the 18th century, the town gained notable momentum in local urbanization with the growth of the olive oil and soap industries in Western Anatolia (Uçar, 2013; Özker, 2020).

Fig. 1. Urban conservation and natural protected areas with satellite imagery of the study area

By the 19th century, Ayvalık had developed into a settlement predominantly inhabited by a Greek population, characterized by its educational institutions, religious buildings, and examples of civil architecture. This socio-cultural development played a decisive role in shaping the housing pattern and the overall morphology of the settlement (Niğdelioğlu Çamkaya, 2023). However, social unrest in 1821 and a major earthquake in 1865 led to the destruction of a significant portion of the building stock, necessitating the reconstruction of the town. During the reconstruction process, traditional planning principles were preserved, although Western architectural influences also began to appear in the settlement (Kıyak, 1997; Akın, 2007). Ayvalık continued its architectural and cultural development until the beginning of the 20th century. The 1923 population exchange between Türkiye and Greece marked a profound transformation in the socio-cultural structure of the town. Although the user profile changed with the exchange, the original architectural character of many buildings was largely preserved in the following years (Niğdelioğlu Çamkaya, 2023). In 1976, Ayvalık was designated as an "urban conservation area" by the High Council of Immovable Antiquities and Monuments, initiating the implementation of conservation policies within the settlement. Nevertheless, these conservation efforts could not entirely prevent the spatial transformations that occurred over time (Özker, 2020). From the 1980s onward, increasing population pressure and the impact of tourism led to the deterioration of some structures, while others were restored in ways that were incompatible with their original authenticity.

2.2 Structural Development

The traditional settlement pattern of Ayvalık was shaped by its relationship with street orientations, parcel organization, and topography, gradually developing a natural character over time (Kıyak, 1997). The streets were oriented perpendicular to the prevailing winds from the north and northeast, known locally as the "Poyraz", facilitating the penetration of cool airflows into the settlement during the summer months (Aslan, 2018). Narrow and shaded design of the streets limited direct solar radiation throughout the day, helping to prevent overheating and creating a microclimate that enhanced passive cooling. While a more regular, grid-like parcel organization is observed in flatter areas, the streets on sloped terrains adapt organically to the topography, changing direction in response to the landform. This adaptation not only maintains visual connections with the surrounding landscape but also supports natural air circulation across the settlement (Kıyak, 1997; Akın, 2015).

The building-scale approaches that developed in parallel with this settlement pattern also define the structural characteristics of Ayvalık traditional houses. This architectural identity emerged at the intersection of geographical conditions and cultural accumulation, blending the use of local materials, climate-adaptive solutions, and construction techniques of the period to create a distinct regional character. Typically constructed in a row-house arrangement, these houses are generally two or three stories high (Erdem et al., 2007). The ground floors were built using load-bearing stone masonry, while the upper floors employed a timber frame system. In this composite construction method, the ground floors were often built with Sarımsak Stone, a local material prized for its ease of carving and its aesthetically pleasing pinkish hue. This material contributed significantly to both the structural integrity and the architectural expression of the buildings. On the upper floors, a lighter and more flexible system known as the "bağdadi" technique was applied (Niğdelioğlu Çamkaya, 2023). In this technique, the timber frame was covered with reeds or wooden laths, then finished with lime-based plaster (Fig. 2) (Asımgil & Erdoğdu, 2013). Thanks to this construction method, the upper floors, often featuring oriel window, are visually and physically separated from the stone-built ground floors. With their pastel-colored plastered surfaces, these facades make a characteristic contribution to the distinctive street silhouette of the settlement.

Fig. 2. An example of the "bağdadi" construction technique in Ayvalık traditional houses

The use of wood in Ayvalık traditional houses was not limited to structural elements; it also contributed to the aesthetic and characteristic identity of the buildings through details such as window shutters and ceiling decorations. Iron was also widely used, serving both functional and decorative purposes in window grilles, balcony railings, and door knockers (Uztuğ, 2006; Efe, 2019). Architectural features formed by the use of these materials, such as oriel window, wide eaves, doors, and windows, are the distinctive elements that define the aesthetic expression of Ayvalık traditional houses. These features introduce both horizontal and vertical articulation to the facades, thus collectively shape the silhouette of the settlement within the street pattern (Akın, 2015).

Following the settlement pattern and structural features previously described, an examination of the spatial organization of Ayvalık traditional houses reveals that the ground floors were predominantly organized for commercial purposes, incorporating service areas such as storage and kitchens, along with rooms opening onto the courtyard (Tibet, 2013). The upper floors, on the other hand, functioned as the main living spaces of the houses. In most examples, two separate external entrances provided direct access to both the ground floor, typically used for storage, and the upper floor, where the living spaces were located. Additionally, internal access between the ground and upper floors was often provided by an interior staircase (Efe, 2019). Another important space on the upper floor that connected the rooms was the "sofa". Generally designed in an inner sofa layout, this space functioned not only as a circulation area but also as a place for sitting, resting, and daily living activities. The rooms were mostly arranged along the long sides of the sofa, while balconies, staircases, or external openings were often located at the short sides in some examples (Erdem et al., 2007). The sofa was intentionally designed to promote natural ventilation and daylight and served as a livable central space within the house. A schematic floor plan example of Ayvalık traditional houses is presented in Fig. 3.

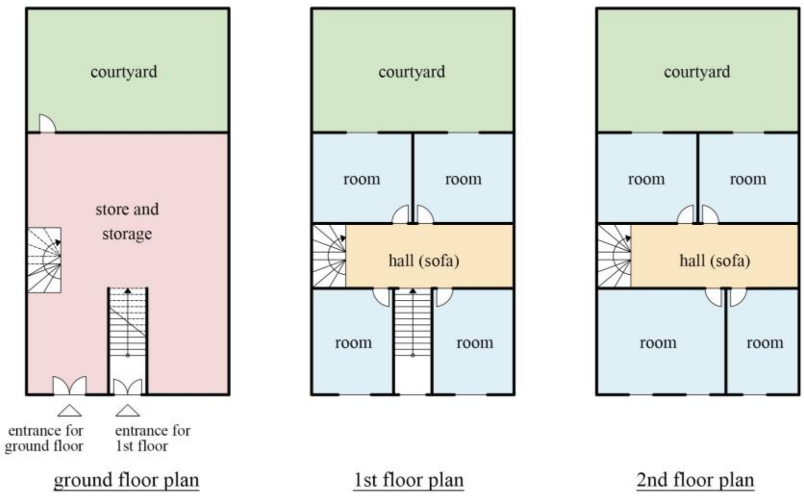


Fig. 3. A schematic floor plan example of Ayvalık traditional houses

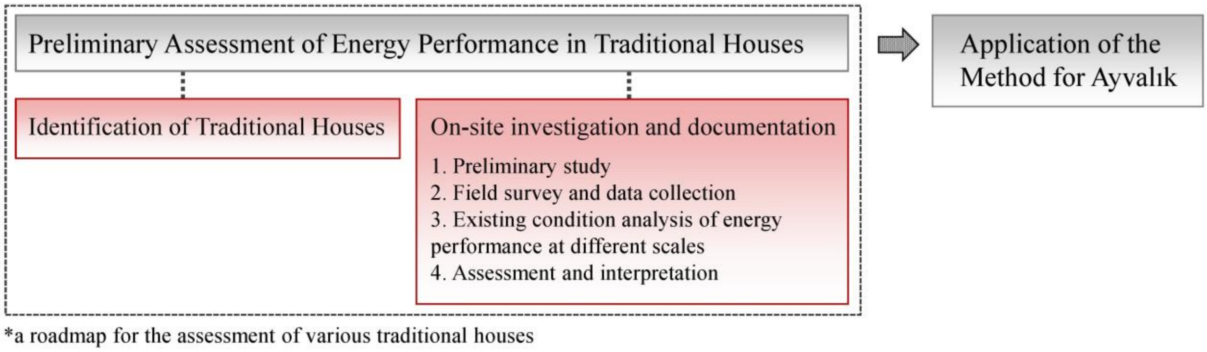


Fig. 4. Stages of the proposed method

3. Preliminary assessment of energy performance in traditional houses

In this section, a preliminary assessment method is proposed to provide a foundation for studies focusing on the energy performance of traditional houses. The method aims to systematically examine the building and settlement characteristics and to document the findings, thereby establishing a basis for future energy analyses. Furthermore, the method is designed to be applicable to traditional houses located in different climatic regions, and in this study, it is exemplified through its application to Ayvalık traditional houses. The methodology comprises the identification of traditional houses to be evaluated in terms of energy performance, followed by on-site investigation and documentation. Within this framework, a comprehensive and systematic preliminary assessment method has been developed through observations and analyses conducted at the settlement, building, and building envelope scales for Ayvalık traditional houses. Fig. 4 summarizes the stages of the proposed method.

3.1 Identification of traditional houses to be assessed in terms of energy performance

The settlement of Ayvalık traditional houses is characterized by a compact urban pattern formed by narrow streets, organic parcel structure, and stone-timber structures. Within this settlement, six traditional houses with different locations and orientations were selected based on their ability to reflect the region's unique architectural character and their relevance for representing energy performance through passive design strategies. The selection process was guided by specific criteria. These included the spatial arrangement of buildings, distances between structures, and orientation at the settlement scale, as well as the internal spatial organization and façade properties at the building scale. These houses were then examined on-site according to the defined criteria. Their locations and parcel information are shown on the Ayvalık settlement map in Fig. 5.

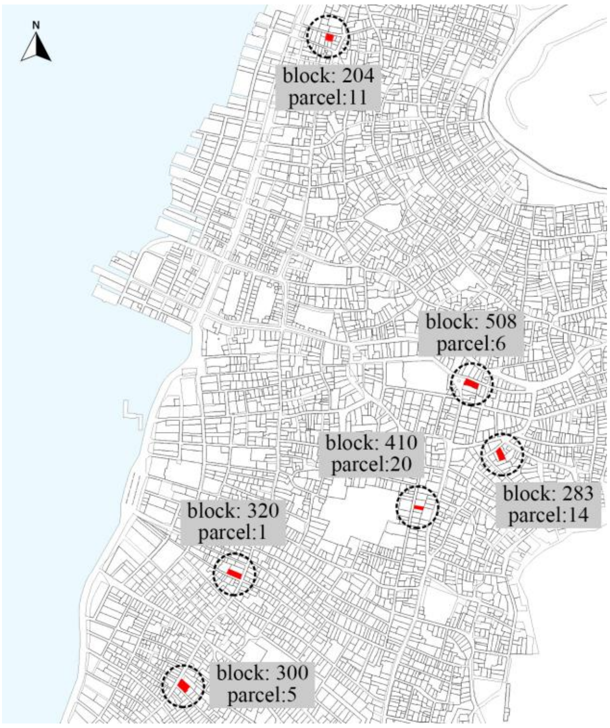


Fig. 5. Location and parcel information of the traditional houses assessed within the scope of the study

3.2 On-site investigation and documentation

On-site investigation and documentation is among the fundamental stages of the restoration process in historical buildings, enabling the analysis of their existing conditions. The data gathered during this process is also critical for conducting energy performance analyses aimed at ensuring the sustainable use of historic structures. Based on this approach, the present study proposes a systematic preliminary assessment method for evaluating the energy performance of traditional houses, inspired by on-site investigation practices commonly employed during restoration works (Yazgan, 2023; Ahunbay, 2016; Kudeb, 2009; Republic of Türkiye Ministry of Culture and Tourism, 1983a; 2012b). The proposed method defines systematic data collection steps that can guide future studies focused on the energy performance of traditional buildings. These on-site investigation and documentation stages were applied to the Ayvalık traditional houses and are presented in Table 1. It was observed that the ground floors of the houses consisted of load-bearing stone walls, utilizing Sarımsak Stone, a material specific to the region. In the upper floors, a timber frame system was employed, and the "bağdadi" technique was applied.

4. Application of the method for Ayvalık

In this section of the study, Ayvalık traditional houses were analyzed in terms of energy performance based on on-site investigation and documentation stages. Accordingly, the six traditional houses identified in Section 3.1 were examined and observed in detail during the site visit. The details of the building components in the selected Ayvalık traditional houses were determined through project documentation and field survey.

Table 1. On-site investigation and documentation stages for assessing the energy performance of traditional houses

On-site investigation and documentation	
1. Preliminary study	Site selection
	Initial review based on the location and orientation of traditional houses within the settlement plan
	Literature and archival review to document the historical background of the traditional houses
	Examination of official records related to traditional houses, such as registration and conservation status
2. Field survey and data collection	During the survey: recording the overall condition, surroundings, and architectural details of the selected traditional houses through photography and preliminary measurements
	Requesting existing restoration project documentation of the selected houses from relevant institutions
	In the absence of such documentation, prepairing measured drawings (plan, section, elevation) and identifying material details
3. Existing condition analysis of energy performance at different scales	At the settlement scale: environmental and climatic assessment including building surroundings, distances to neighboring buildings or obstacles, adjacency relationships, building orientation, solar exposure, and ventilation conditions, etc.
	At the building scale: spatial and typological analysis including floor plan layout, spatial organization, functional distribution, relationships between spaces, ceiling heights and number of floors, etc.
	At the building component scale: identification of materials used in building components (external walls, roof, groundfloors, and windows) through project documents or field surveys; calculation of overall heat transfer coefficients (U-values) in accordance with the TS 825 standard; determination of transparent component details (glazing type, frame type), and assessment of shading devices, etc.
	Identification of areas requiring intervention in terms of energy performance and detection of physical damages
4. Assessment and interpretation	Assessment of the transmissivity of the building's opaque and transparent components according to TS 825
	Development of improvement proposals for the building's opaque and transparent components

All of the roofs were designed as either hipped or gabled roofs. In this context, the overall heat transfer coefficients (U-values) of the building components were calculated to evaluate the energy performance of the selected traditional houses. These U-values were compared with the recommended maximum U-values for the second climatic zone (characterized by a mild-humid climate) as specified in the TS 825 "Thermal Insulation Requirements for Buildings" standard (TS 825, 2024) (external walls: 0.4 W/m²K, roofs: 0.3 W/m²K, ground-contact floors: 0.35 W/m²K, and windows: 1.8 W/m²K). The data obtained contribute to a better understanding of the architectural characteristics of traditional houses and their potential for user-centered sustainability. In addition, these findings aim to provide a foundation for developing new strategies for the contemporary built environment. A detailed analysis of on-site investigation and documentation for the assessment of energy performance in the selected Ayvalık traditional houses is presented in Table 2.

The Ayvalık traditional houses addressed in terms of energy performance were examined and analyzed according to the on-site investigation and documentation stages proposed within the scope of the study. In the first stage, the locations of the traditional houses were identified on the settlement plan. In the second stage, the selected houses were examined on-site through observation, and an archive was created by photographing their general conditions, surroundings, and architectural details. Subsequently, the restoration projects of the houses were requested from the relevant institutions. The examination revealed that restoration projects had been completed for five of the houses, while information was obtained indicating that one house (House 5) was scheduled for restoration. In the third stage, the existing condition of the selected traditional houses was analyzed at different scales (settlement, building, and building component) in terms of energy performance.

At the settlement scale, the location of the selected traditional houses, their relationship with neighboring buildings, street layout, orientation, solar exposure, and ventilation conditions were examined. Three of the houses are located on corner plots, while the other three follow a row-house typology. This distinction affects the surface area directly exposed to external climatic elements. The analysis also focused on the main façade -where the entrance is located- and its exposure to climatic factors such as sun and prevailing winds (northeast and southeast). Regarding solar exposure, it was found that the main façades of five houses were either directly or partially exposed to sunlight, while one house (House 1), whose main entrance faces north, benefited only from reflected solar radiation. As for ventilation conditions, plan-based analysis showed that three of the six houses were oriented to benefit from both northeast and southeast winds, two houses received ventilation primarily from northeast winds, and one house was not directly exposed to the prevailing winds. These findings demonstrate that the influence of external climatic elements such as sun and wind may vary from house to house. Narrow streets were also observed within the settlement. These streets facilitate natural ventilation by channeling prevailing winds and create shaded areas through surrounding buildings, thereby reducing solar heat gains. Such spatial configurations contribute not only to improved pedestrian comfort but also indirectly enhance the cooling energy performance of the houses.

At the building scale, the selected traditional houses were examined in terms of spatial organization, functional distribution, and the relationships between interior spaces. It was observed that the ground floors of the houses are used as storage areas, while the upper floors serve as living spaces. This functional division is also evident in the entrance configuration: one of the two doors at the front opens to the ground-floor storage area, while the other leads to the living space above. In the analyzed houses, the upper floors generally have higher ceiling heights than other levels. This design strategy likely allows hot air to rise, preventing heat accumulation in the main living areas. As a result, thermal discomfort caused by warm indoor air is reduced, and a cooler indoor environment is maintained. Additionally, the placement of living spaces on the upper floors may have been preferred to take greater advantage of natural ventilation. This planning approach corresponds with the typical layout scheme widely observed in the traditional settlement pattern of Ayvalık (Fig. 3). Other planning strategies observed in Ayvalık include the use of oriel windows (cumba) and courtyards, both of which are commonly found in the analyzed houses. Through oriel windows, the number of openings increases, allowing for improved natural lighting and the creation of shaded areas on the façade. Courtyards also provide shaded areas throughout the day, offering users a chance to cool down. Thus, these traditional planning strategies contribute significantly to both indoor and outdoor thermal comfort, as well as to the overall energy performance of the houses. In terms of current use, three of the houses function as hotels, two are used as residences, and one remains unused, as it has not yet been restored.

At the building component scale, information on the materials used in the selected traditional houses was obtained through field surveys and architectural project documents. Based on this data, the heat transfer coefficients (U-values) of the components were calculated in accordance with the TS 825 standard. In the selected houses, Sarımsak Stone was commonly used on the ground floor, particularly in external walls and floors in contact with the soil. In contrast, the upper floors featured timber frame systems in both external walls and roofs. Due to these material differences, U-value calculations were carried out separately for each floor. As shown in Table 2, the results indicate that the U-values of the components exceed the recommended threshold values defined by TS 825. However, the wall construction technique (stone + infill + stone) results in a high thermal mass in the building envelope. This may help maintain indoor comfort during both heating and cooling seasons, regardless of the U-value. Due to the material and technological limitations of the period these houses were built, the thermal resistance of the building envelope is relatively low. This is a common characteristic observed in cooling-dominant regions.

Table 2. Detailed analysis of on-site investigation and documentation for the assessment of energy performance in the selected Ayvalık traditional houses

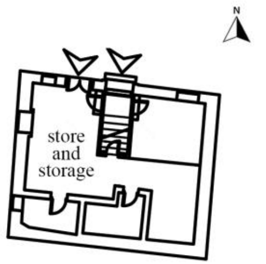
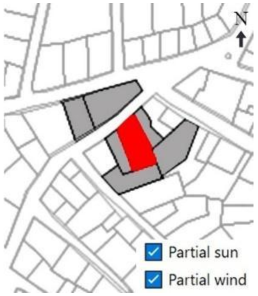
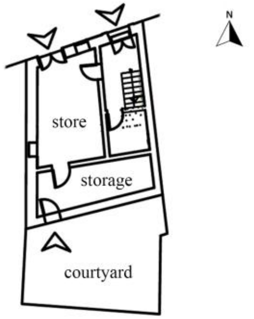
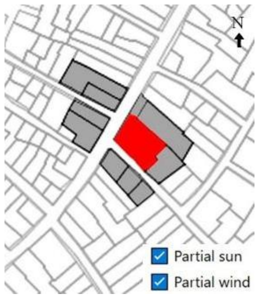
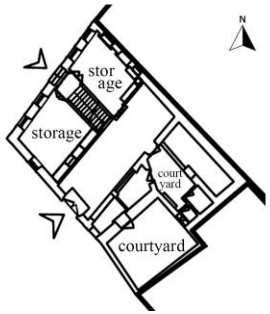
1. Preliminary study		2. Field survey and data collection		3. Existing condition analysis of energy performance at different scales (3.1 Settlement, 3.2 Building and 3.3 Building component)					4.Assessment and interpretation
				3.1		3.2		3.3	
Block - Parcel	Site Plan	Existing view	Conservation status	Environmental and climatic assessment	Orientation	Ground floor plan	Function	Uvalue	Uvalue (TS825)
204 - 11 (Sakarya Neighborhood, Cumhuriyet Street, 11.Alley)			Restored		North		Hostel	**Wall:** G: 1,92 1st: 1,92 2nd: 1,68 **Roof:** 0,67 **Floor:** 1,92	**Wall:** 0,4 **Roof:** 0,3 **Floor:** 0,35
283 - 14 (Zekibey Neighborhood, 13 Nisan Street)			Restored		North North-West		Hostel	**Wall:** G: 1,66 1st: 2,33 2nd: 1,42 **Roof:** 0,82 **Floor:** 1,92	**Wall:** 0,4 **Roof:** 0,3 **Floor:** 0,35
300 - 5 (Hayrettinpaşa Neighborhood, Barbaros Street, Futbol Meydanı Alley)			Restored		North-West		House	**Wall:** G: 1,66 1st: 1,76 **Roof:** 0,98 **Floor:** 1,92	**Wall:** 0,4 **Roof:** 0,3 **Floor:** 0,35

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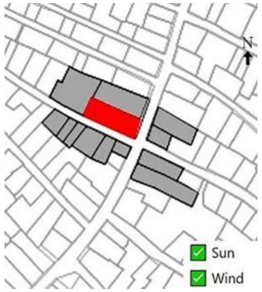
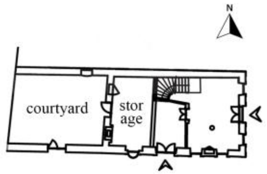
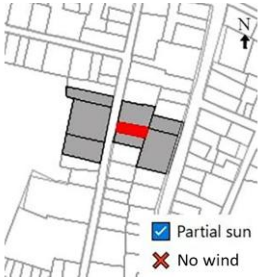
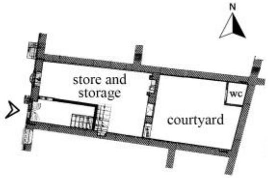
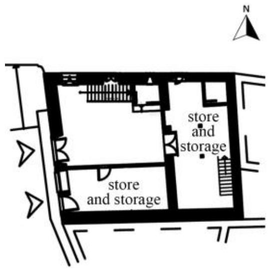
Table 2. continued

1. Preliminary study		2. Field survey and data collection		3. Existing condition analysis of energy performance at different scales (3.1 Settlement, 3.2 Building and 3.3 Building component)					4.Assessment and interpretation
				3.1		3.2		3.3	
Block - Parcel	Site Plan	Existing view	Conservation status	Environmental and climatic assessment	Orientation	Ground floor plan	Function	Uvalue	Uvalue (TS825)
320 - 1 (Hayrettinpaşa Neighborhood, Barbaros Street, 13. Alley)			Restored		South		House	**Wall:** G: 1,87 1st: 2,22 2nd: 2,41 **Roof:** 0,78 **Floor:** 1,92	**Wall:** 0,4 **Roof:** 0,3 **Floor:** 0,35
410 - 20 (Zekibey Neighborhood, Zafer Alley)			Ruined (will be restored)		West		-	**Wall:** G: 2,06 1st: 1,81 **Roof:** 0,67 **Floor:** 1,92	**Wall:** 0,4 **Roof:** 0,3 **Floor:** 0,35
508-6 (Hamdibey Neighborhood, Alibey Cami Street, Nalbantlar Alley)			Restored		West		Hostel	**Wall:** G: 1,66 1st: 1,28 **Roof:** 0,59 **Floor:** 1,92	**Wall:** 0,4 **Roof:** 0,3 **Floor:** 0,35

In such climates, passive cooling strategies such as shading devices, narrow wind-ventilated streets, high ceilings, oriel windows, and courtyards tend to be prioritized. As for transparent components, their thermal performance was also found to be limited, primarily due to the common use of single glazing. To support thermal performance, most of the windows are equipped with wooden shutters, which function as shading elements that help reduce overheating in summer and limit heat loss during winter.

In summary, the analysis indicated that the opaque and transparent components of the selected traditional houses do not meet the performance criteria defined by TS 825. Therefore, it is necessary to develop improvement strategies to enhance their energy performance under the climatic conditions of the region. These strategies should focus particularly on opaque components and be designed in a way that preserves the original material use and construction techniques of traditional architecture. This approach would support both the conservation of architectural authenticity and the improvement of indoor comfort conditions for users.

5. Results

In traditional houses, it is essential not only to preserve their architectural and environmental characteristics but also to ensure indoor user comfort for the sustainability of life in these buildings. Based on this necessity, the study adopted a multi-scalar approach to assess Ayvalık traditional houses in terms of energy performance and proposed a roadmap to support design decisions that enhance thermal comfort. In this context, a systematic preliminary assessment method was developed for future research on energy performance, incorporating on-site investigation and documentation stages. Accordingly, a preliminary assessment was conducted on six traditional houses located within the urban conservation area of Ayvalık. The architectural characteristics of the houses and their relationship with the environment were examined, ranging from the settlement scale to the material scale.

In Ayvalık, it has been observed that cooling strategies are prioritized due to the region's climatic characteristics, directly shaping planning strategies at both the settlement and building scales. At the settlement scale, the analysis of energy performance revealed that the location and orientation of the houses, their relationship with neighboring buildings, and the presence of narrow streets affect solar heat gains and natural ventilation potential. It was also observed that houses located on corner plots are more exposed to external climatic conditions compared to those built in a row-house typology. However, the orientation of façades and the spatial organization should also be considered key design features for maximizing the benefits of sunlight and wind. At the building scale, the analysis focused on features such as floor plan layout, spatial organization, functional distribution, relationships between spaces, ceiling heights and number of floors. These features provide insights into both user comfort and the energy performance of the houses. For example, higher ceilings may support cooler indoor conditions, while courtyards can provide shaded outdoor areas. Oriel windows contribute not only to shading but also improve daylight access through an increased number of windows. The current functions of the houses also influence their energy consumption. At the building component scale, the analysis was based on the heat transfer coefficient (U-value) thresholds recommended in the TS 825 Standard. Accordingly, it was found that the U-values of wall and floor components constructed with Sarımsak Stone and timber frame systems exceed the recommended limits. This indicates that, under current conditions, these houses have potential for energy performance improvement. In addition, wooden shutters on the windows can be considered another climate-responsive strategy at the component scale, as they help reduce overheating in summer and minimize heat loss in winter. In light of these findings, it was concluded that assessing the energy performance of traditional houses is essential. However, in future studies, the thermal mass performance of the building envelope can be quantitatively determined through measurements and supported by modeling and simulation tools to estimate annual energy loads of the buildings.

In conclusion, the preliminary assessment method developed and exemplified through the case of Ayvalık traditional houses has provided a foundation for future research. The sustainability of traditional houses depends on both the preservation of their historical features and the improvement of their energy performance. Accordingly, this study offers a basis for advanced simulation-based analyses and emphasizes the importance of energy performance-oriented approaches in traditional settlements. Therefore, it will be possible to create sustainable and energy-efficient living environments for the future while preserving the valuable heritage of the past. Future studies may focus on proposing alternative building component improvement strategies and innovative material solutions in accordance with restoration principles. Simulation tools can also be used for a more detailed analysis of indoor thermal comfort conditions. Finally, assessing the energy performance of traditional houses under future climate scenarios could be considered another important research topic.

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An examination of the illumination levels of vertical circulation elements in historical buildings: Stair towers of the old Edirne Train Station building

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Abstract. Circulation elements are building elements that serve the purpose of connecting spaces either horizontally or vertically, facilitating the movement between spaces located at different places or levels. One such element is stairs, which, while being the most fundamental circulation component in architecture, can have various designs and details depending on the architectural style and period. In this context, stair towers, especially those designed as part of public buildings or historical structures, not only give monumental character to the buildings but also include window openings that allow natural light to penetrate into the interior spaces. This study will evaluate the natural lighting conditions of the stair towers in the historic train station building, designed by Architect Kemaleddin and currently used by the Faculty of Fine Arts at Trakya University, which is an example of early 20th-century Republican era civil architecture. The arrangement of the existing window openings and the level of daylight will be analyzed. In this scope, using the Dialux Lighting Simulation program, the distribution of natural light within the space and, where necessary, the effectiveness of artificial lighting will be assessed, and the functional and practical applications of past design dynamics will be discussed.

Keywords: Circulation Elements; Natural Lighting; Dialux; Train Station Buildings; Stair Towers.

1. Introduction

The luminous atmosphere created in both interior and exterior spaces plays a significant role in maintaining individuals' circadian rhythms, influencing circadian systems that regulate daytime cycles and endocrine secretions (Öney & Balcı, 2021). In architectural structures, various luminous functions and requirements exist depending on different spatial functions. These are established through a combination of factors such as appropriate lighting design, correct use of light sources, adjustment of color temperature, and control of light intensity.

Circulation areas are spaces that facilitate movement and establish connectivity between different interior and exterior parts of a building. These areas are designed to ensure that users can move safely and efficiently. Although they are not typically spaces where individuals spend extended periods of time, the provision of physical and visual comfort in these transitional zones is crucial to support purposeful actions. Therefore, lighting in these areas must be functionally appropriate and accurately implemented. Within architectural terminology, horizontal circulation areas refer to corridors, while vertical circulation areas include staircases, elevators, ventilation shafts, lighting wells, and certain open spaces such as gardens, courtyards, or plazas located outside buildings.

This study focuses on stair towers, which historically served both as vertical circulation elements and as prominent architectural features.

2. Materials and Methods

In this study, the architectural lighting simulation software Dialux Evo 4.0 was utilized. DiaLux, a program used for both interior and exterior lighting design, allows for spatially based simulations of both natural and artificial lighting data. It was employed to determine the levels of natural and artificial lighting within the stair towers of the Old Railway Station (currently the administrative building of Trakya University Faculty of Fine Arts), which is characterized by insufficient natural illumination. Initially, the amount of daylight-based illumination was measured independently from artificial lighting; subsequently, the existing artificial lighting levels were assessed.

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The study proposes a lighting scenario addressing the necessary number and type of lighting fixtures required to meet the minimum illuminance levels as defined in lighting standards.

3. Architectural Circulation Spaces and Daylight Requirements From Past to Present

Circulation elements in architectural structures facilitate both horizontal and vertical movement, ensuring connectivity between spaces. These elements not only enable transitions between different levels but also hold architectural significance in terms of aesthetics and functionality. From antiquity to the present, the form and characteristics of these elements have evolved according to architectural periods. The historical development of vertical circulation elements, particularly staircases, can be categorized into six distinct periods.

In ancient times, staircases emerged as functional necessities, as seen in Mesopotamian ziggurats and Egyptian pyramids. During the Greek and Roman periods, stairs acquired aesthetic value, with Romans constructing larger and more ornate staircases using arch and vault systems. In the Middle Ages, spiral staircases became common in castles and cathedrals for defense and spatial efficiency. Renaissance stair design gained artistic expression, which was further enriched with decorative elements during the Baroque and Rococo periods. The 19th century introduced steel and reinforced concrete, leading modernist architects to design functional, minimalist stairs inspired by industrial architecture and nautical themes. Le Corbusier, through his concept of the "architectural promenade," favored ramps and sculptural stair designs (Templer, 1992; Arığ, 2023; Canbakal-Ataoğlu, 2024).

In 20th-century modern architecture, circulation elements were primarily shaped by principles of functionality and efficiency. Staircases and elevators were designed not only for vertical transport but also as integral components of spatial aesthetics. They were strategically positioned to interact with environmental factors—especially natural light—enhancing the luminous and spacious quality of interiors and enriching spatial experience. Thus, circulation areas were carefully planned to fulfill functional needs while also contributing to architectural aesthetics. Stair lighting plays a crucial role in both safety and visual enhancement. A well-designed lighting scheme ensures safe usage while improving the overall spatial appearance. Despite the widespread use of elevators in the postmodern period, staircases remain essential architectural elements for guiding circulation, especially in public buildings (Templer, 1992; Canbakal-Ataoğlu, 2024).

3.1. Lightning Requirements for Staircases

To ensure safe use, staircases must be equipped with appropriate lighting conditions. Both national and international standards emphasize lighting requirements for stairs in terms of user safety, comfort, and energy efficiency. A well-designed lighting system not only promotes safety but also enhances the spatial atmosphere.

Stair lighting must meet requirements for safety, functionality, and aesthetics. Adequate illuminance levels should ensure clear visibility of steps and edges; a minimum of 100 lux per step is recommended. Uniform and consistent light distribution is essential to prevent shadows and dark areas, thus enabling secure movement (TS EN 12464-1:2012).

Motion sensor technologies may be employed to improve energy efficiency and user experience, activating lihgts only when needed and reducing unnecessary energy consumption, particularly in dark environments. Aesthetic and functional considerations should guide lighting design; decorative fixtures, wall sconces, or chandeliers may be used in alignment with the architectural style, but functionality must remain a priority.

Today, LED lighting is one of the most preferred methods for stair illumination due to its energy efficiency and long lifespan, offering both economical and environmentally friendly solutions. Various color temperatures can be used to influence spatial ambiance. In narrow or spiral staircases, a sensitive lighting design is crucial. Properly planned lighting systems enhance both safety and architectural harmony. Moreover, smart technologies enable lighting levels to be adjusted according to user needs, optimizing energy use

3.2. Illuminance Standards for Vertical Circulation Elements

Stair towers and other circulation components have become essential in architectural design for facilitating natural lighting. The admission of natural light enhances user experience and positively influences spatial ambiance. The positioning, facade orientation, and structural features of staircases are key factors in directing light into the space. In particular, glass surfaces used in stair tower design play a critical role in introducing daylight into interiors. These applications offer advantages in terms of both aesthetics and energy efficiency. As a result, circulation spaces become brighter and more spacious while also ensuring visual comfort.

Additionally, illuminance reference values for the safe and effective use of vertical circulation elements are specified by both national and international standards. In Turkey, stair lighting is regulated by TS EN 12464-1:2012 and the Regulation on Fire Protection of Buildings (Ministry of Environment and Urbanization). According to these:

- TS EN 12464-1:2012 requires a minimum of 100 lux for staircases in enclosed spaces.
- The Fire Protection Regulation mandates at least 1 lux for emergency routes and escape stairs.
- Steps must be lit to prevent shadows, glare, and ensure visual comfort.

Internationally, standards such as ISO 8995-1, CIE 60, BS 5489, NFPA 101 (Life Safety Code), and IEC 60598 address stair lighting:

- ISO 8995-1 (CIE 60): Minimum 100 lux for interior stairs, 20 lux for exterior stairs.
- BS 5489: Recommends 5 lux for outdoor stairs and 15 lux for frequently used areas.
- NFPA 101: Requires at least 1 lux for emergency exits and stairways.
- IEC 60598: Regulates the electrical safety and energy efficiency of stair lighting fixtures.

Table 1 provides a comparison of national and international standards regarding stair lighting and associated energy efficiency criteria. Both TS EN 12464-1 and ISO 8995-1 mandate a minimum of 100 lux for enclosed stairs. NFPA 101 and Turkish regulations require at least 1 lux in emergency exits. While the UK and other countries have additional requirements for exterior stair lighting, such regulations are not clearly specified in Turkish standards.

Below is a table comparing national and international standards (Table 1).

Table 1. Comparison of National and International Standards

Criteria	**Türkiye (TS EN 12464-1:2012)**	**ISO 8995-1 (CIE 60)**	**BS 5489 (United Kingdom)**	**NFPA 101 (USA)**
Indoor Staircase Lighting	100 lux	100 lux	-	-
Outdoor Staircase Lighting	Not specified	20 lux	5-15 lux	-
Emergency Lighting	1 lux	1 lux	-	1 lux
Energy Efficiency and Safety	Compliant with IEC 60598	Compliant with IEC 60598	Compliant with IEC 60598	Compliant with NFPA 101

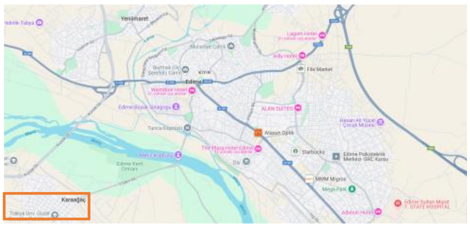
4. Field Study: Stair Towers of Trakya University Faculty of Fine Arts

To emphasize the importance of natural lighting in railway station buildings, the historical railway station located in Karaağaç, in the central district of Edirne, was selected as a case study. Within the scope of the study, the current condition of the building will be examined in detail, and its adequacy in terms of natural lighting will be assessed. Where necessary, artificial lighting scenarios will be proposed to supplement deficiencies.

4.1. Location and Characteristics of the Building

The Karaağaç Train Station, formerly known as Edirne Railway Station (Fig.1, Fig. 2) is a historical structure located on Karaağaç Street in the Karaağaç neighborhood of Edirne. The original station, constructed during the Ottoman period by the Chemins de fer Orientaux / Rumelia Railway (CO) Company, was inaugurated on April 4, 1873. However, due to increasing demands for passenger and freight transport over time, it was decided to construct a larger and more monumental station building. The new station, designed in a neoclassical style by the prominent architect Kemaleddin, was inspired by the design of the Sirkeci Railway Terminal in Istanbul. The resulting structure is an impressive, three-story, rectangular building measuring 80 meters in length. It served as one of the most important stops on the railway line connecting Istanbul to Europe. Today, the station remains a significant cultural and historical landmark and is considered one of the key elements of Edirne's architectural heritage (URL1, Başar & Erdoğan, 2009; Hasanbat, 2018).

Before being allocated to the Faculty of Fine Arts, the building served various functions throughout its history. Between 1872 and 1977, it operated as the Edirne Train Station; from 1977 to 1982, it housed the Edirne State Academy of Engineering and Architecture; from 1982 to 1994, it served as the Trakya University Edirne Vocational School; and between 1998 and 2011, it functioned as the Rectorate and Administrative Offices of Trakya University (Meral, 2016). In 2011, the building was transferred to the Faculty of Fine Arts, where it underwent restoration and adaptive reuse. Today, the ground floor accommodates the administrative offices and exhibition halls of the Faculty of Fine Arts. The upper floor, where the stair towers under study are located, currently functions as a guesthouse for the university.



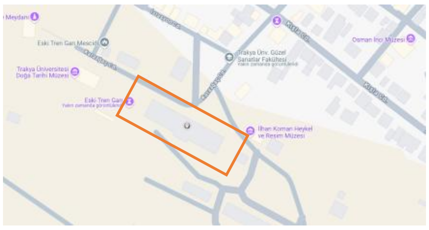


Fig. 1, Fig. 2. The Location and Urban Context of the Faculty of Fine Arts, Trakya University, Edirne

4.2. Architectural Features of the Building

The Edirne Railway Station was constructed as a three-story building, including a basement, aligned parallel to the railway tracks. As with earlier railway station buildings, it reflects the typical characteristics of railway station typology. The building is symmetrically organized along the axis of the central ticket hall entrance. The central and end volumes are emphasized by projecting them beyond the main facade plane and raising them above the roofline, highlighting the symmetrical layout. This emphasis is further accentuated by a pair of cylindrical towers capped with pointed wooden domes, symmetrically placed on either side of the central block, facing the entrance to the station (Fig. 3).

The station building, measuring 80 meters in length and 16 meters in width, was constructed using a brick masonry wall system (Fig. 4, Fig. 5). The exterior walls of the central section, which includes the three-story ticket hall, as well as the window and door arches, moldings, and the upper parts of the towers, were built with ashlar stone. Volta flooring system was used for the floors, and the building is covered with a hipped roof made of asbestos sheets supported by steel trusses (Edirne Inventory of Immovable Cultural Assets, 2013).

On the facades of the building, the basement floor windows are designed with segmental arches, while the ground and first-floor windows feature pointed arches. The windows on the ground floor are wider and taller than those on the upper floors, allowing for increased daylight penetration and contributing to a balanced visual composition. The main entrances on both the city-facing and platform-facing sides of the station are marked by large, pointed arches extending across the entire height of the structure, glazed to allow natural light in. These arches are framed with wide moldings, giving them the appearance of monumental portal gates. The upper ends of the towers—also accessible from the exterior—feature enclosed balconies defined by twelve pointed-arched openings, each supported by short columns. The building's facade composition is further enhanced by buttresses at specific points and wide-banded eaves, which together create a harmonious architectural expression.

Approaching the building from the city side, two cylindrical towers with circular plans and pointed domes—considered symbolic elements of the Edirne Railway Station—can be observed. These cylindrical towers are positioned on either side of the main hall and are set back from the main entrance block. Their placement within the architectural plan was made possible by the inclusion of single-storey service areas with terrace roofs and parapet railings.

Inside the towers, access to the terrace is provided by a helical staircase (Fig. 6), illuminated by natural light through four pointed-arched windows—two on the front facades and two on the side facades—of two different sizes. As the tallest structural elements of the building, the towers are fully visible from the northeastern facade adjacent to the main entrance block. When viewed from the southwestern facade (towards Greece), only the domes of the towers are discernible.

Designed with a circulatory function, the towers house spiral staircases that allow access to the first floor, attic, and the terrace level of the tower. The domes feature enclosed terraces made more prominent by twelve arched openings supported by columns.

The tower masses of the station building extend from the chamfered corners of the structure up to the first-floor level, and the form transitions at the parapet level are shaped by the repetition of various geometric forms and stone moldings along the facade, giving the tower a cylindrical surface. The towers, iconic symbols of the station, are topped with onion-shaped, lead-covered domes. Today, only one of the staircases—located in the left tower and leading to the Dean's Office—remains in use. This staircase can be accessed both from the interior and the exterior. Upon reaching the first floor, one arrives at the administrative staff level; at the start of the second floor, access to the main building's attic space is provided; and at the top level, the tower's terrace is reached—although it has been observed that the area leading to the terrace has been closed off.

Based on the data obtained regarding the building, the natural illumination levels of the staircase towers and the entrance hall have been identified and evaluated in detail.

Fig. 3 Photographs of the Exterior Facade of the Administrative Building of the Faculty of Fine Arts, Trakya University (Elif Polat Archive, 2025)

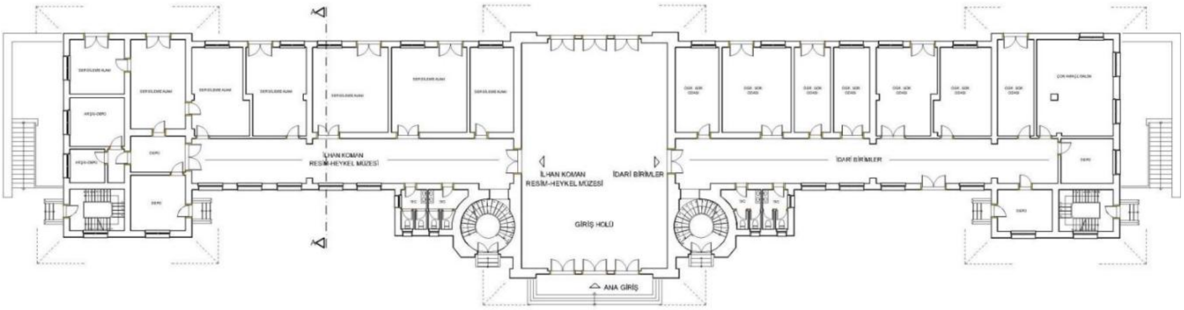


Fig. 4 Measured Survey Project of the Edirne Train Station Building (Faculty of Fine Arts, Trakya University), Ground Floor Plan (Archive of the Department of Construction and Technical Works, Trakya University)

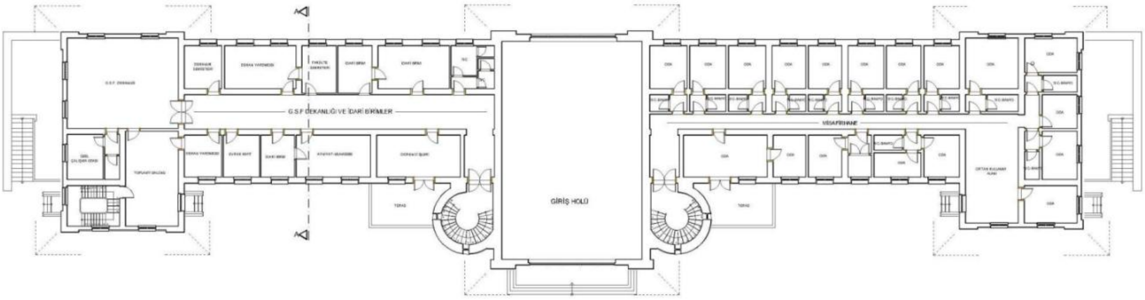


Fig. 5 Measured Survey Project of the Edirne Train Station Building (Faculty of Fine Arts, Trakya University), First Floor Plan (Archive of the Department of Construction and Technical Works, Trakya University)

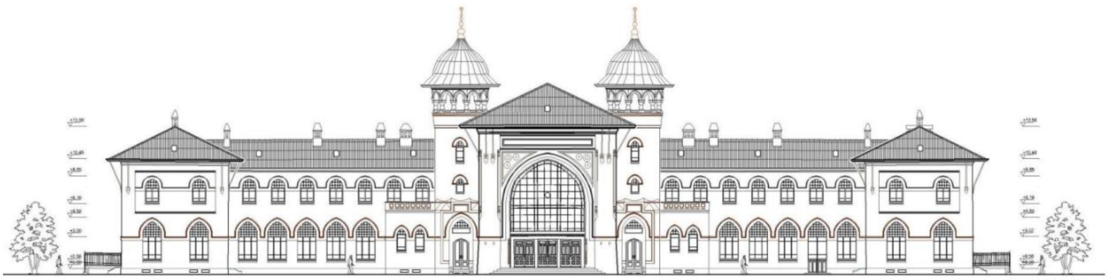


Fig. 6 Measured Survey Project of the Edirne Train Station Building (Faculty of Fine Arts, Trakya University), First Floor Plan and Entrance Facade (Archive of the Department of Construction and Technical Works, Trakya University)

Fig. 7, Fig. 8, Fig. 9 Interior Photographs of the Stairwell Tower of the Administrative Building, Faculty of Fine Arts, Trakya University (Elif Polat Archive, 2025

4.3. Evaluation of the Natural Daylight Levels of the Towers

Within the tower, a helical staircase that provides access up to the terrace level is illuminated by natural light through four pointed-arched windows (Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12), consisting of two on the front facades and two on the side facades, in two different sizes (Fig. 13, Fig. 14). The pointed-arched windows of smaller height are used at the lower levels of the tower, whereas the larger-sized windows are employed from the first floor up to the terrace level. This difference in window size results in a perceptible increase in the level of natural illumination in the upper sections of the tower.

As stated in Section 2.2, the required illuminance level for staircases, ramps, and escalators is specified as 100 lux (TS EN 12464-1:2012; URL2) (Fig. 15, Fig. 16). The same illuminance value of 100 lux shall also be adopted for the towers located within the workspace.

A daylighting analysis was conducted using the Dialux lighting simulation software for the main entrance hall of the building and the stairwell towers located on either side (Fig. 17, Fig. 18, Fig. 19).

In the ground floor plan of the structure, due to the absence of windows in the stair towers and the fact that this level is illuminated solely by natural light entering through the large windows of the main entrance hall, the measured illuminance level was found to be 25 lux. On the first floor of the towers, daylight enters through four pointed-arch windows, yielding an illuminance level of 500 lux in areas adjacent to the windows, while the surrounding areas recorded values ranging between 100 lux and 300 lux (Fig. 19).

An analysis of false-color lighting distribution in the main entrance hall revealed illuminance levels of 250 lux in areas near the windows and 100 lux in zones farther from them. Since these levels comply with the prescribed standards and provide sufficient lighting, no additional artificial lighting has been deemed necessary for this section. In the following section, a proposed artificial lighting scenario is presented for the ground floor, where natural illumination proves insufficient.

Fig. 10, Fig. 11, Fig. 12 Photographs Showing the Natural Lighting Conditions of the Ground Floor of the Stairwell Tower (Elif Polat Archive, 2025)

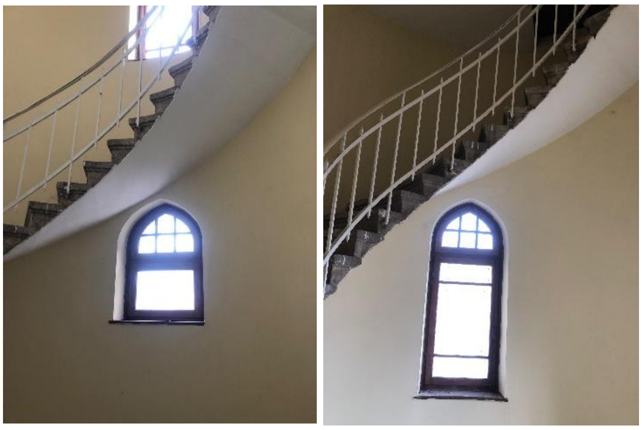


Fig. 13, Fig. 14 Photographs of Two Different Types of Windows Used in the Tower (Elif Polat Archive, 2025)

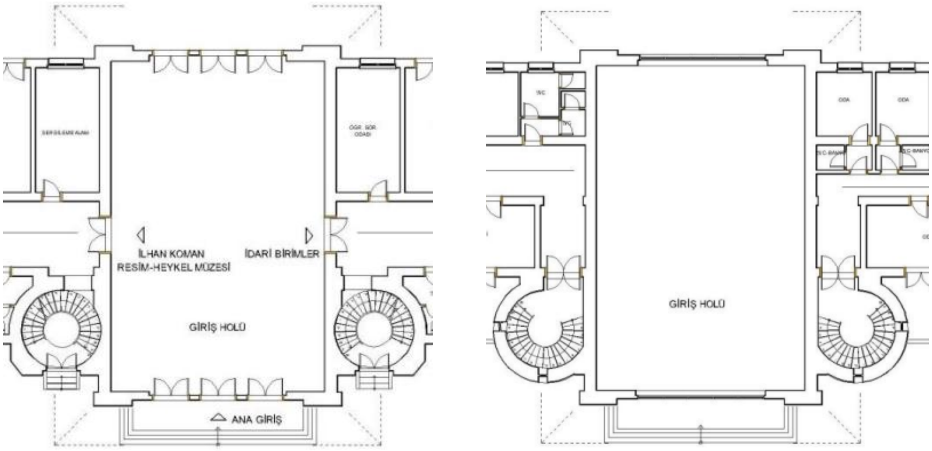


Fig. 15, Fig. 16 Measured Survey Project of the Edirne Train Station Building (Faculty of Fine Arts, Trakya University), Areas to be Measured for Illuminance Levels in the Ground Floor and First Floor Plans (Archive of the Department of Construction and Technical Works, Trakya University)

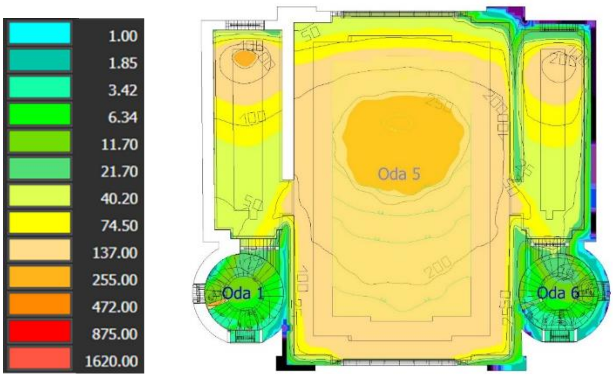


Fig. 17 Natural Illuminance Level Measurement Results (DiaLux Evo)

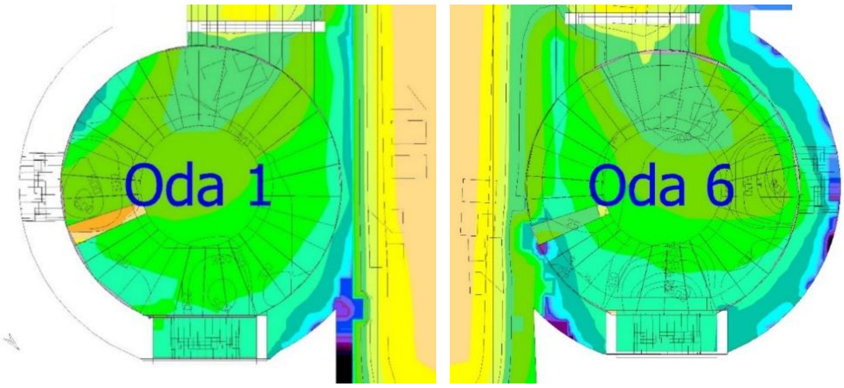
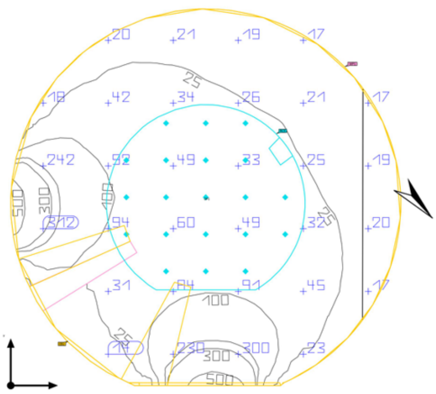


Fig. 18 Natural Illuminance Measurement Results of the Stairwell Towers Located on the Left and Right of the Building (Room 1 and Room 6) (DiaLux Evo)

Structure 1- Ground Floor- Room 1 (Lightning stage for daylight ratios)

Summary



Floor surface 3.22 m²

Degree of reflection
Ceiling: 37.7%
Walls:49.7%
Ground: 20.0%

Height of free space 10.950 m

Height 8.600 m

Maintenance multiplier 0.80 (lump)

Border region (working plane) 0.000 m

Structure 1- Ground Floor- Room 1 (Lightning stage for daylight ratios)

Summary

Results	Magnitude	Calculated	Nominal	Check	Index
Working Plane	Uo (g1) Vertical	72.3 lx	≥ 100 lx	✗	WP1
	Uo (g1)	0.16	≥ 0.40	✗	WP1
Main surfaces of the room	E Ceiling	9.39 lx	≥ 100 lx	✗	RC5
	Uo (g1) Ceiling	0.52	≥ 0.10	✓	RC5
Visual task areas	E Work zone	166 lx	≥ 100 lx	✓	ET2
	Uo (g1) Work zone	0.16	≥ 0.40	✗	ET2
	E Ambient zone	-	≥ 100 lx	✗	ES2
	Uo (g1) Ambient zone	-	≥ 0.40		ES2
	E Background area	-	≥ 33.3 lx	✗	EB2
	Uo (g1) Background area	-	≥ 0.10		EB2
Consumption quantities	Consumption	0.00 kWh/a	maks. 150 kWh/a	✓	
Area	Specific connection value	0.00 W/m²	-		
		0.00 W/m²/100 lx	-		

(1) A rectangular area of 2,038 m x 1,968 m and SHR value of 0.25 is taken as basis.
(2) Calculated with DIN:18599-4.
Usage profile: circulation zones inside the building (9.2 stairs, walking bands and elevators)
Planning information: Daylight for overcast sky on 20.01.2025 12.00 (UTC+03.00 Istanbul)
Ambient conditions for 'Room 1' are normal

Fig. 19. Natural Illuminance Measurement Results of the Stairwell Tower Located on the Left Side of the Building (Room 1) (DiaLux Evo)

4.4. Proposed Lighting Model for Stair Towers

Artificial lighting is required in zones where natural daylight fails to provide adequate illumination, and it serves to enhance brightness levels through controlled energy consumption. Accordingly, for the ground floor of the structure under study, the proposed model incorporates lighting fixtures along the ceiling and sidewalls of the tower entrance, as well as within the transitional section connecting the tower to the main volume. This strategy aims to enhance energy efficiency in general lighting while also creating a safer and more effective circulation zone.

Whereas the current design includes only a single artificial lighting fixture on the ground floor, the proposed model utilizes a total of three artificial lighting units—specifically, the LAMP brand's Moody G2 800 WW FL Triac BK fixtures—to achieve optimal and sufficient illumination. A false-color representation of the proposed model is illustrated in Fig. 20.

According to Fig. 21, the months with the highest demand for lighting are identified as January and December, with 17:00 being the time of day requiring the most illumination. (The calculations were made based on a five-day work week and operating hours between 07:00 and 18:00.)

In the proposed lighting scenario, user comfort in circulation areas has been ensured, and a direct, zonal, and energy-efficient lighting strategy has been implemented. The scenario supports the specific illuminance needs of each zone. As a result of this lighting proposal, the interior lighting levels of the towers have reached the 100 lux standard as cited in the literature and mandated by regulations for circulation areas. This configuration meets the minimum illumination requirements necessary for efficient circulation, in accordance with relevant standards.

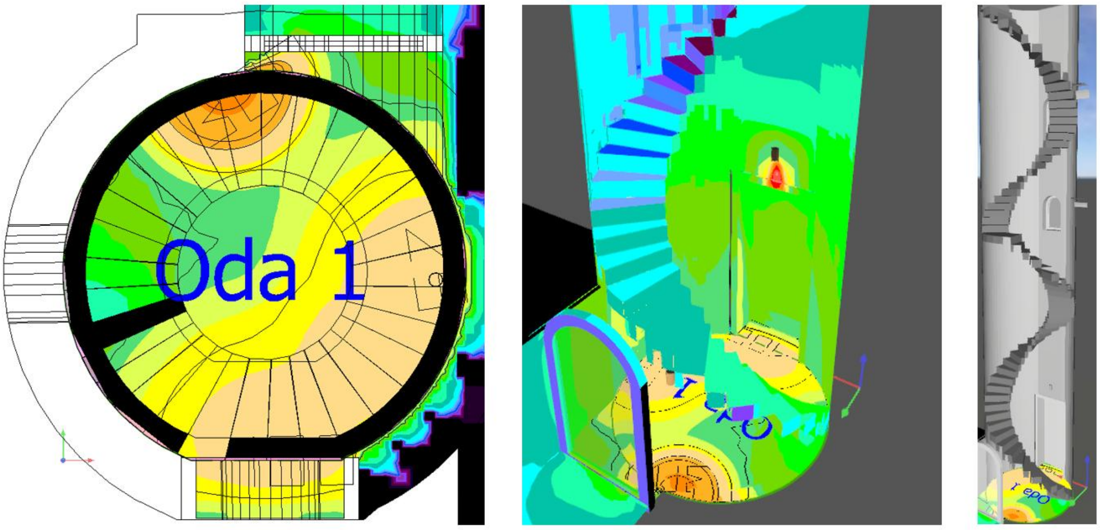


Fig. 20 Analysis of Incorrect Colors in the Stairwell Tower Located on the Left Side of the Building (Room 1) (DiaLux Evo)

An energy consumption analysis has been conducted using the fixtures employed in the study, and the variation of the analysis results by month is presented in Fig. 21.

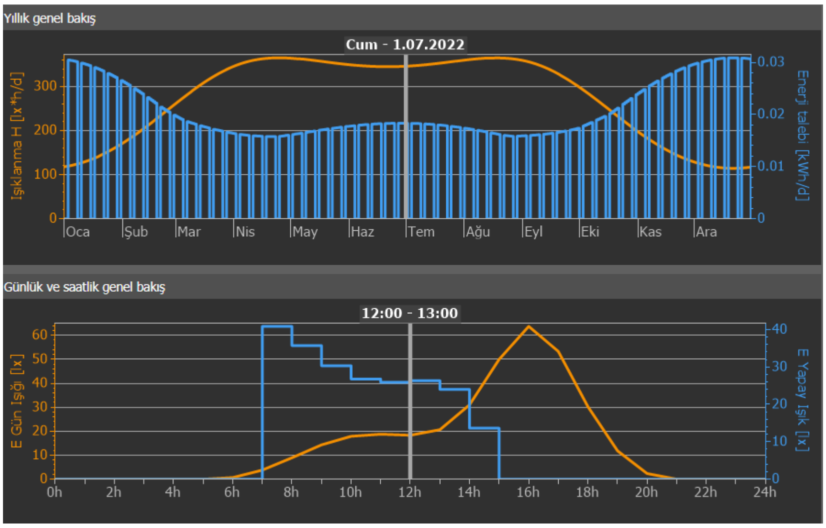


Fig. 21 Annual Energy Demand Measurement Results of the Stairwell Tower Located on the Left Side of the Building (Room 1) (DiaLux Evo)

5. Conclusions

Since daylight is insufficient to provide adequate illumination in certain areas of the stairwell towers, lighting proposals suitable for circulation zones have been developed in accordance with the findings of this study. In the proposed scenario, the illuminance level required for circulation functions has been achieved based on the relevant standards, ensuring adequate lighting for operational needs. Furthermore, both direct and indirect artificial lighting have been evaluated in terms of their impact on energy consumption. Proper and adequate illumination of staircases—which play a crucial role in facilitating vertical circulation—and the spaces housing them, is also critical for accident prevention.

This study focuses on the illuminance levels of the main entrance hall and the stairwell towers of the historical Edirne Train Station, which currently serves as the Faculty of Fine Arts building at Trakya University. The adequacy of lighting in these areas has been assessed. It was found that the natural lighting levels in the main hall, considered the entrance foyer, and the upper floor hall connected via the stairs, are sufficient during working hours. However, while the first-floor stairwell lighting level is adequate for functional use, the ground floor level is insufficient. Therefore, a scenario incorporating artificial lighting fixtures for the ground floor was proposed to achieve the required illuminance levels. The energy consumption of the proposed artificial lighting is observed to increase, particularly during the winter months (December and January).

In the case of historical buildings, evaluations regarding daylight levels are made based on the original facade and spatial design at the time of construction. Structural interventions that may alter the building's authenticity are typically restricted, aside from necessary conservation-related modifications. Thus, existing openings have been preserved in their current form, and an artificial lighting scenario was developed accordingly. Furthermore, the change in the building's function does not necessitate alterations in lighting requirements for the circulation areas addressed in this study. The requirements of staircases, as vertical circulation elements, remain consistent across different periods and functions. Therefore, the continued functional integrity of the stairwell towers, and their role as the sole means of vertical circulation within the building, underscore the significance of this study. The outcomes of this research aim to guide future studies concerning the assessment and proposal of both natural and artificial lighting strategies in historical buildings.

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Fig. 3, Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12, Fig. 13, Fig. 14: Elif Polat Photography Archive (2025).

Fig. 4, Fig. 5, Fig. 6, Fig. 15, Fig. 16: Project Archive of the Department of Construction and Technical Works, Trakya University.

Fig. 17, Fig. 18, Fig. 19, Fig. 20, Fig. 21: DiaLux Evo data.

Birecik Bridge in the context of long span reinforced concrete bridges: An architectural and structural analysis

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Abstract. Birecik Bridge is considered as an important structure that stands out in the process of Turkey's rural development policies in the 1950s and the construction of modern engineering structures in Anatolia. In addition to exhibiting Turkey's engineering capacity in terms of the period in which it was built, it also had a strategic importance in terms of facilitating the transportation of the surrounding agricultural rural area with the urban area. Located over the Euphrates River in the Southeastern Anatolia Region, the bridge is one of the longest reinforced concrete bridges in Turkey with a length of 720 meters. The structural systems used in the design of Birecik Bridge, which is an indicator of the development of reinforced concrete bridge technologies in Turkey, made it possible to cross large spans in an economical and durable way. The main purpose of this study is to examine and document the architectural and structural features of Birecik Bridge, an important architectural heritage for Turkey. The data obtained through literature review and fieldwork were systematically evaluated to analyze aspects of the bridge such as design, material use and durability. The study and documentation of the bridge sheds light on the history of engineering and architecture in Turkey and provides a scientific reference for the conservation and restoration of similar structures in the future. Thus, the bridge is considered in its historical context as a structure that demonstrates the role of modern engineering and architecture in regional development.

Keywords: Birecik bridge, Reinforced concrete bridge, Long span bridges, Architectural heritage, Sanliurfa

1.Introduction

Bridges are not merely structures that facilitate transportation; they are also critical architectural and urban planning elements that support the spatial continuity of cities, integrate with the landscape, and contribute aesthetically to urban identity. Located in Turkey's Southeastern Anatolia Region, the district of Birecik has historically served as a strategic center, enabling crossings over the Euphrates River and standing out as a key junction point within local and international trade networks (Paydaş & Narin, 2022; Bilici, 2024).

Due to the natural barrier formed by the Euphrates River, transportation in the region faced considerable challenges throughout history, and crossings were for a long time conducted using primitive methods (Onüçyıldız et al., 2016; Öğün & Başı, 2016). Within this context, the Birecik Bridge, inaugurated in 1956, was regarded not only as an engineering achievement but also as a tangible manifestation of the modernization initiatives, rural development policies, and transportation strategies of the Republic of Turkey.

As part of the development programs initiated in the 1950s, the integration of rural areas with urban centers was targeted, with investments in highways and bridge constructions aiming to enhance rural-urban interaction (İnan & Konyalı, 2022). In this regard, the Birecik Bridge contributed to regional development by connecting Southeastern Anatolia's production hubs to industrial and foreign trade routes, assuming a symbolic role in reducing the infrastructural disparities between the eastern and western parts of the country (Yurddaş, 2019).

From an engineering perspective, the Birecik Bridge represents a significant milestone in the development of long-span reinforced concrete bridge technology in Turkey. Featuring wide arch spans and hybrid structural systems, the bridge successfully combined durability with economic solutions, reflecting the technical capabilities of its time (URL-1).

Globally, long-span reinforced concrete bridges came to prominence in the late 19th century with advancements in materials and engineering, as the compressive and tensile strengths of reinforced concrete enabled large spans to be crossed economically (Billington, 1979). By the mid-20th century, innovations such as prestressed concrete technology and segmental construction methods further expanded spans and redefined the balance between aesthetics and engineering requirements in bridge design.

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In Turkey, the widespread use of reinforced concrete bridges accelerated during the post-World War II period (Tanrıverdi and Gürel, 2019). While early examples featured small to medium-span arch systems, the Birecik Bridge, completed in 1956 with an approximate span of 180 meters, became one of the most significant crossings realized using reinforced concrete in the country (Bayraktar et al., 2013). This process paved the way for the widespread adoption of long-span bridge construction across Turkey, particularly with the later embrace of prestressed concrete technologies.

Today, many long-span reinforced concrete bridges are being constructed in Turkey using contemporary techniques such as segmental casting, prestressed concrete, and hybrid systems. The viaducts of the Northern Marmara Motorway, the approach viaducts of the 1915 Çanakkale Bridge and the major crossings along the Ankara-Niğde Motorway exemplify the advanced state of concrete bridge engineering in the country.

This study aims to examine the Birecik Bridge from both architectural and structural perspectives and to reveal the socio-spatial impacts of infrastructure investments during Turkey's modernization process. Supported by a literature review and field observations, this analysis seeks to demonstrate that the bridge serves not only as a transportation structure but also as a multilayered architectural heritage reflecting the ideological, technological, and societal vision of its era.

2.Materials and methods

The primary material of this study is the Birecik Bridge, located in the district of Birecik in the province of Şanlıurfa, within the Southeastern Anatolia Region of Türkiye. A multi-stage methodology was adopted in order to comprehensively analyze the architectural and structural features of the bridge. The research process consists of three main phases: a literature review, archival investigation, and fieldwork.

In the first phase, the historical development of reinforced concrete bridge technology, the evolution of long-span bridges, and academic studies related to the Birecik Bridge were systematically examined. In the second phase, project documents belonging to the Şanlıurfa Regional Council for the Protection of Cultural Assets Archive, the General Directorate of Highways, and the 9th Regional Directorate of Highways were analyzed; data regarding the construction process, technical specifications, and conservation efforts of the bridge were collected. Furthermore, by utilizing photographic archives from previous years, the physical changes of the bridge were assessed.

In the final phase, the fieldwork involved on-site observations of the bridge, where the load-bearing system components, material properties, and current structural condition were documented in detail. The on-site examinations contributed to both the evaluation of the bridge's conservation status and the verification of the findings derived from the literature and archival research.

3.Results and discussion

The Birecik Bridge stands among the significant engineering achievements of its time, brought to life through detailed and meticulous work. With decision No. 549 dated 15.11.2007, the bridge was registered as an immovable cultural asset requiring protection by the Şanlıurfa Regional Council for the Protection of Cultural Assets under the Ministry of Culture and Tourism. Subsequently, with decision No. 657 dated 30.06.2008, the same Council granted permission for minor repairs. In this context, practices such as the renewal of the railings, asphalt resurfacing, lighting, and expansion joint repairs were carried out. On 09.07.2014, decision No. 1122 approved the prepared survey, restitution, and restoration projects by the Şanlıurfa Regional Council for the Protection of Cultural Assets.

The bridge is located between the Birecik Dam upstream and the Karkamış Dam downstream. The waters released from the Birecik Dam are stored in the Karkamış Dam Lake, with the bridge situated within the boundaries of this lake basin. During the construction of the Karkamış Dam, ground improvement works were carried out using the jet grouting method to protect the foundations of the bridge and ensure impermeability. In 2009, an accident occurred on the bridge: a fuel-carrying vehicle fell from the 12th span and caught fire, causing damage to the bridge's load-bearing elements. The maintenance and repair works on the expansion joints and guardrails of the bridge mentioned above were carried out by the 9th Regional Directorate of Highways in 2008. As of 2014, a comprehensive project was prepared and presented for the repair and reinforcement of the bridge.

3.1. Architectural features of the Birecik Bridge

Throughout history, humans have sought to live near water; in particular, freshwater sources such as streams and rivers have been favored as settlement sites. The historic city of Birecik, shaped by settlements along the Euphrates River, played a role that was heavily dependent on the river for the development of transportation and trade. In particular, small boats and rafts remained the primary means of transportation for crossings from the city center to the western side for many years. However, with the increasing volume of trade and evolving transportation needs, the necessity for a permanent structure became apparent. In this context, the Birecik Bridge, inaugurated in 1956, represented a strategic step that supported the region's economic and social development.

One of the longest reinforced concrete road bridges in Türkiye, the Birecik Bridge is located on the E-90 highway and forms a critical transportation corridor, particularly for the Şanlıurfa-Gaziantep axis (Fig.1). The bridge was designed with a total length of 694.6 meters and a width of 10.54 meters, utilizing 44,000 bags of cement and 921 tons of iron (The Şanlıurfa Regional Council for the Protection of Cultural Assets Archive, 2025). On either side of the deck, there are pedestrian sidewalks constructed with reinforced concrete blocks, integrated with metal railings and lighting poles.

In terms of architectural design, segmental arch systems were employed on the eastern side (towards Birecik), while beam systems were used towards the west (Gaziantep side). Progressing from east to west, the initial span is crossed with a flat deck, followed by five segmental arches each with a span of 55 meters over the main riverbed (Sert et al., 2015). The deck, supported by square-sectioned columns following the curvature of the arches, is carried by 24 columns under each arch span.

Fig.1. Early construction period of the Birecik Bridge (The Şanlıurfa Regional Council for the Protection of Cultural Assets Archive, 2025)

On the eastern bank, a retaining wall extends along the Euphrates River, providing support to the bridge. The segmental arch section spans approximately 300 meters. After the seventh pier, the bridge transitions into a beam system supported by 13 rectangular piers towards the west (Fig. 2.). The beam section of the deck measures approximately 400 meters in length. In the structural design of the bridge, plain steel reinforcement was used, with the piers reinforced by triangular-sectioned cutwaters and toe details on both the upstream and downstream sides. Recognized as an original example of Republican-era bridge engineering in Türkiye, the Birecik Bridge was registered by the Şanlıurfa Regional Council for the Protection of Cultural and Natural Assets in 2007 and continues to serve two-way vehicular and pedestrian traffic today.

Fig. 2. View of the bridge’s reinforced concrete beam section from the west bank; the reinforced concrete beam system supporting the deck slab; view of the bridge’s reinforced concrete arch section from the east bank (Personal Photograpy Archieve of Author, 2025)

3.2. Structural features of the Birecik Bridge

The Birecik Bridge is located in the Birecik district of Şanlıurfa province, oriented in an east-west direction over the Euphrates River, along the Şanlıurfa-Gaziantep route (Fig 3). Opened in 1956, this bridge is an important engineering work from the Republican Era, with a total length of 720 meters and a width of 10 meters. At the time of its construction, it held the title of Turkey’s longest reinforced concrete highway bridge and today it is classified as a registered cultural heritage (URL-2).

Two different load-bearing systems were used together in the bridge. On the eastern side (Şanlıurfa direction), where the main bed of the Euphrates River is deeper, a reinforced concrete arch system was implemented. On the western side (Gaziantep direction), a variable cross-section reinforced concrete beam system was preferred. Additionally, the first span on the eastern side near the Birecik city center was designed as a flat-deck transition.

Fig. 3. Views of the bridge from the north side toward the south, and from the east side toward the west side (General Directorate of Highways Archive)

The distribution of the load-bearing systems along the east-west direction, span by span, is as follows:
1st Span: With a span of 20 meters, constructed with a variable cross-section reinforced concrete beam. It is used as a pedestrian and vehicle underpass (Fig. 4.). The piers are clad with cut limestone, and the beam height measured from the black elevation is approximately 5.10 meters.

Fig. 4. View from 1st Span of the Birecik Bridge, which is used as a pedestrian and vehicle underpass (Personal Photograpy Archieve of Author, 2025)

Spans 2–6: Each consists of segmented reinforced concrete arches with a span length of 55 meters. (Bayraktar etal., 2013).The radius of the arches is approximately 52.43 meters. The bridge arches are rigidly connected in the middle parts and at the side piers, and are constructed with joints at the upper points of the right and left parts of the middle points of the arches.The heights from the black level (reference elevation) to the crown points are measured as 5.15 m for span 2, 13.05 m for span 3, 15.65 m for span 4, 14.45 m for span 5, and 12.30 m for span 6. In addition, there is a flood protection wall constructed by the State Hydraulic Works (DSİ) at span 3.

7th-20th Spans: Consist of variable cross-section reinforced concrete beam systems, each with a 26-meter span. Gerber beam system with hinged expansion joints are located at the 8th, 11th, 14th, and 17th spans (Fig. 6.). A pedestrian staircase detail is present at the 12th span. The foundation piers, columns, beams, and decks of the bridge's arch and beam systems were entirely constructed of reinforced concrete. However, the support details at the end points of the arch and beam sections could not be fully determined from existing documents.

When examining the deck heights relative to the black elevation in the beam system spans, the following values were recorded: 8.70 meters at the 7th span, 10.60 meters at the 8th, 8.70 meters at the 9th, 8.15 meters at the 10th, 6.80 meters at the 11th, 5.60 meters at both the 12th and 13th, 4.10 meters at the 14th, 4.70 meters at the 15th, 4.30 meters at the 16th, 5.40 meters at the 17th, 4.60 meters at the 18th, 5.50 meters at the 19th, and 5.30 meters at the 20th span (The Şanlıurfa Regional Council for the Protection of Cultural Assets Archive (2025). *Archival documents on Birecik Bridge)*.

According to the technical report prepared during the restoration and repair works carried out in 2014, it was determined that BÇI type plain reinforcement steel was used in the bridge. Tests performed on concrete cores revealed that the concrete strength class was between C25-C30 in the arch sections and between C20-C30 in the beam sections.Today, the Birecik Bridge is open to both pedestrian and vehicular traffic, allowing the passage of normal vehicles, passenger buses, and heavy-duty trucks.

The Euphrates River, over which the Birecik Bridge stands, is the longest and most water-rich river in Turkey. With a total length of about 2800 kilometers, 1263 kilometers of the river lies within Turkey's borders. The flow regime of the Euphrates River is quite regular; water levels rise between March and June, and a gradual decrease is observed from July to January. Large-scale hydroelectric dams such as Keban, Karakaya, Atatürk, Birecik, and Karkamış have been constructed on the river, making these structures strategically important for the region's energy production and water management.

4.Conclusions

Within the scope of this study, the structural and architectural features of the Birecik Bridge, located in the Southeastern Anatolia Region of Turkey and built in 1956, have been comprehensively examined. The analyses show that the bridge serves not only as a means of facilitating transportation but also plays a decisive role in the region's economic development and socio-economic transformation. Especially by strengthening the connection between the east and west, this bridge has indirectly contributed to the increase in agricultural and livestock activities observed around the Euphrates River.

From a structural point of view, the Birecik Bridge incorporates advanced engineering solutions for its time. Considering that reinforced concrete and girder systems were only beginning to be used in the early 20th century, the bridge's design — combining both reinforced concrete arch and girder systems to balance the pressure and tensile forces caused by water — stands out as a significant approach that enhances structural durability.

Over time, corrosion-related deterioration has occurred on the bridge piers submerged in water, and wear on the load-bearing elements has been observed due to increased vehicular load. In this context, the registration of the Birecik Bridge as a cultural asset in 2007 has further emphasized the importance of its preservation.

In order to ensure the bridge's transmission to future generations as a long-lasting cultural heritage element, several restoration and conservation strategies have been developed. Within this framework; detailed material analyses of the original load-bearing elements should be conducted, intervention methods specific to different types of deterioration should be determined, and the principle of minimum intervention should be adopted during restoration to preserve the original structural character of the bridge. In addition, the heavy vehicle load on the bridge should be reduced, and alternative transportation routes should be planned for this purpose. It is also recommended to establish structural health monitoring systems to monitor the bridge's future performance and to take early precautions against potential risks.In conclusion, it is expected that the conservation and restoration proposals developed for the Birecik Bridge will form a methodological framework for the sustainable preservation of historic reinforced concrete bridges and contribute to the academic literature.

Acknowledgments

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Graphite's multifunctional effects on thermal properties in construction materials

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Abstract. Management of thermal energy plays an important role in reducing energy consumption to provide an optimum environment within the building. It is known that approximately 30-40% of the total energy consumption worldwide originates from the construction sector and a large amount of this energy is wasted for heating and cooling purposes. Therefore, improving the thermal insulation properties of the buildings is of great importance in order to save energy by reducing energy losses. The thermal conductivity and volumetric heat capacity of a wall are two properties that greatly affect building's energy performance. The heat storage capacity of the material relies on its high specific heat and density, with high thermal conductivity facilitating rapid heat transfer during storage, while thermal insulation is achieved through a low thermal conductivity component or surrounding material. Graphite, a black and gray carbon mineral, is sourced from nature and increasingly produced synthetically by recycling lithium-ion batteries, driven by the rapid rise in battery production. Consequently, its availability has spurred widespread use in industries like electronics and energy storage, with its potential applications in architecture, such as thermal management now under research. The high thermal conductivity of graphite can be used to increase the heat storage capacity of materials, and in applications such as when it is included in expanded polystyrene, its radiation scattering property contributes to reducing thermal conductivity, thereby improving insulation performance. As a result, the use of graphite in architecture offers great potential in terms of increasing energy efficiency. In this study, the existing literature on the classification, properties, usage and potential of graphite in architectural materials within the scope of thermal energy management is reviewed and evaluated.

Keywords: Graphite; thermal conductivity; radiation; material; architecture.

1. Introduction

The demand for increasing the energy efficiency of buildings has increased significantly since energy use in the building sector constitutes a significant portion of total energy consumption and greenhouse gas emissions worldwide (Jelle, 2011). Considering the exhaustible nature of energy resources, global warming and increasing economic costs, energy efficiency in the construction sector has become a priority. According to the International Energy Agency (2024), a large portion of global energy consumption originates from the construction sector; a significant portion of the sector's energy use consists of heating and cooling needs, which are affected by climate conditions and economic development trends. In particular, the fact that a large part of the existing building stock has been constructed without considering energy efficiency increases energy losses, and these losses lead to both economic resource waste and environmental carbon emissions. In this context, the Building Energy Performance Directive (BEPTR) in force in Turkey also makes energy classifications of buildings mandatory and encourages energy saving through thermal insulation.

Effective thermal insulation in buildings is of great importance in meeting demands for improved energy efficiency. The increasing energy demand on a global scale and the need to combat climate change have accelerated the search for sustainable and high-tech materials in the construction sector.

One of the basic ways to minimize heat losses is to provide effective thermal insulation in the building envelope. Heat transfer in buildings occurs through three basic mechanisms: conduction, convection and radiation. Thermal insulation is the set of materials or systems used to delay or reduce the heat flow that occurs through these means. Thermal insulation systems can be generally examined under three headings according to the mechanisms by which they are effective against heat transfer:

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In conduction-based insulation, materials with low thermal conductivity coefficients are preferred. These materials minimize conductive heat transfer thanks to their inert air cells. Materials such as stone wool, glass wool, polyurethane foam and expanded polystyrene (EPS) are examples of this group.

Reflective insulation provides protection against heat transfer through radiation. By using materials such as aluminum foil with high reflectance and low emissivity, heat transfer through radiation can be significantly reduced. Radiant barrier systems are practical examples of this approach.

Thermal mass is based on the principle that building elements store heat and transmit it to the interior space in a time-spread manner. Materials such as reinforced concrete, brick and natural stone with high specific heat capacity reduce energy needs by balancing temperature fluctuations and contribute to passive heating/cooling strategies.

Insulation materials contribute to maintaining indoor temperature thanks to their high thermal resistance (R-value) and low thermal conductivity (k-value). Such materials generally limit convection by containing microscopic air gaps (dead air cells); they also reduce the effect of radiation thanks to their low emissivity. Thus, the total effectiveness of the insulation is explained by creating a structure that is not only conductive but also resistant to radiation and convection. The basic principle of thermal insulation is to slow down the heat flow and stabilize the indoor temperature against external factors. In this context, research in the field of building physics has brought to the agenda the development of materials that not only have insulation properties but also have heat storage capacity. Accordingly, optimizing low thermal conductivity and high specific heat capacity in building materials plays a critical role in achieving energy efficiency targets. While low conductivity limits the transfer of temperature fluctuations to the interior; high heat capacity allows the energy to be stored for a long time and reduces the energy consumption of HVAC systems. In this direction, graphite has a remarkable potential due to its unique physical and chemical properties. Thanks to its high thermal and electrical conductivity, resistance to high temperatures, chemical stability and low density compared to metals, graphite is widely used as an industrial raw material in a wide variety of areas such as metallurgy, refractory production, electrochemical devices, sealing elements and lubricants (Çuhadaroğlu & Kara, 2018). In addition to these traditional areas of use, it is thought that properties of graphite such as optical reflectivity can be evaluated in radiation-controlled insulation systems.

On the other hand, graphite is not only a material obtained from natural reserves, but can also be supplied by recycling wastes originating from the use of lithium-ion batteries as anode material and graphite production processes. The study conducted by Liu et al. (2024) shows that graphite production wastes can exhibit photocatalytic activity under visible light and these wastes can be converted into environmentally friendly building materials. Similarly, Kumari & Samadder (2024) conducted studies on the recovery of graphite from end-of-life lithium-ion batteries and its conversion into graphene derivatives. These developments strengthen the contribution of graphite to the sustainable material cycle. Although the effects of graphite on the mechanical strength, electrical conductivity and piezoresistive properties of cement-based composites have been extensively studied in the existing literature, research on its effects on thermal properties is still limited. In particular, studies that address the role of graphite in architectural applications aimed at increasing energy efficiency in building envelopes with a holistic approach are lacking.

This study aims to evaluate the application areas and advantages offered by graphite within the scope of thermal energy management in buildings.

Accordingly, the structure of the study is as follows:

- In the first section, the classification, types and basic properties of graphite will be examined.
- In the second section, the potential use of graphite in architectural applications in the context of thermal insulation, radiation control and thermal mass properties will be discussed.
- In the last section, current limitations and future research and development areas will be evaluated.

2. Graphite: classification and properties

Graphite is one of the four allotropic forms of pure crystalline carbon; the others are diamond, fullerene, and carbon nanotubes (Fig 1). Formed by the arrangement of carbon atoms in a planar honeycomb structure, graphite is a gray-black, opaque mineral with a metallic or earthy luster. Its Mohs hardness varies between 1-2, its density varies between 2.1-2.3 g/cm³, and it has a high melting temperature (3.927°C). With these properties, graphite is a unique material that offers many technical properties such as high temperature resistance, chemical inertness, excellent electrical and thermal conductivity (Olson, 2020; T.C. Enerji ve Tabii Kaynaklar Bakanlığı MTA, 2023; Kaya, 2006; Pierson, 1993). Given these properties, graphite is used in many areas both as a naturally obtained mineral and as a synthetic material produced by industrial processes.

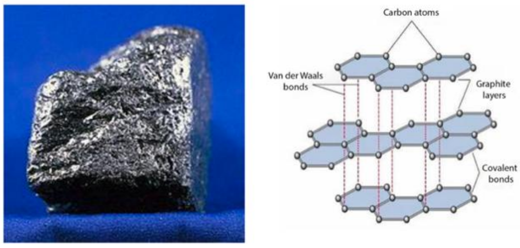

Fig 1. Graphite and structure of graphite (Çuhadaroğlu & Kara, 2018)

Natural graphite is formed in metamorphic rocks through geological processes, while synthetic graphite is obtained by carbonizing carbon sources such as petroleum coke and anthracite at temperatures of 3000–4000°C (IMIB, 2020). Natural graphite is classified into three basic forms: amorphous (microcrystalline), flake and vein type. Amorphous graphite is the most common and low-quality form with a microcrystalline structure and low carbon content. All graphite deposits in Turkey fall into amorphous class and are generally used in metallurgical processes, pencils and brake pads (Kaya, 2006; Jara et al., 2019; T.C. Enerji ve Tabii Kaynaklar Bakanlığı MTA, 2023). Flake graphite has a high carbon content (approximately 85–98%) and is generally found in metamorphic rocks formed under high temperatures and pressures. This type is especially preferred in high-tech fields such as lithium-ion batteries, nuclear reactors and refractory materials. Vein-type graphite is the rarest, highest purity and most valuable type of graphite. It is usually found in Sri Lanka and provides the best thermal and electrical performance with high crystal perfection (Olson, 2020; T.C. Enerji ve Tabii Kaynaklar Bakanlığı MTA, 2023). The physical and chemical properties of the three primary types of natural graphite are summarized in Table 1.

Synthetic graphite has a different environmental profile than natural graphite due to the high energy requirement in the production process. While approximately 4.9 kg of CO_2 is released per kg in synthetic graphite production, this rate is at the level of 1–2 kg CO_2 in natural graphite. In addition, other pollutants such as NOx, SOx and particulate matter are also emitted into the atmosphere during synthetic graphite production (T.C. Enerji ve Tabii Kaynaklar Bakanlığı MTA, 2023). In contrast, synthetic graphite is preferred especially in electrode production, coatings and as a carbon additive due to its advantages such as high purity, controlled structure and chemical stability (IMIB, 2020). A comparison between synthetic and natural graphite is presented in Table 2.

Some intermediate products obtained from graphite reveal the versatile structure of this material. For example, graphene is a single-atom-thick, hexagonally arranged carbon layer obtained from graphite and is called today's "miracle material". Graphene has a current carrying capacity a thousand times greater than copper, 200 times greater strength than steel, and excellent heat conduction. In addition, with its transparent, flexible, and lightweight structure, it has the potential to revolutionize areas such as electronics, defense industry, automotive, and sports equipment (Olson, 2020). Another intermediate product, expanded graphite, is formed by opening its layers like an accordion as a result of high-temperature treatment. This material is used especially in insulation, flame retardant additives, gaskets, and battery technologies with its properties such as low density, high surface area, and electromagnetic protection. Expandable graphite is another form that gains sudden expansion when heated by being subjected to an intercalation process with certain chemicals. Thanks to these properties, it contributes to the development of systems with high energy efficiency (T.C. Enerji ve Tabii Kaynaklar Bakanlığı MTA, 2023).

The physical properties of graphite are also among the factors that determine its areas of use. These properties are presented in Table 3. Its density is low, its hardness is low, but its heat and electrical conductivity properties are quite high. It can be easily flaked due to the weak Van der Waals bonds between the layers, which makes it a natural solid lubricant (Kaya, 2006; Pierson, 1993; Olson, 2020). It is also chemically stable and resistant to most acids, bases and salts. These versatile properties of graphite have made it used in a wide range of applications, from pencils to nuclear reactors, from electrodes to heat-resistant refractory materials. Natural and synthetic forms offer different advantages in different sectors. Natural graphite is mostly used in refractory, casting, pencil and battery production; synthetic graphite stands out in electrode and carbon additive applications where it is required in a purer form (IMIB, 2020).

Table 1. Comparative properties of natural graphite types (Kenan, 1993, as cited in Kaya, 2006)

	Amorphous	**Flake**	**Crystalline**
Carbon (%)	81.00	90.00	96.70
Sulfur (%)	0.10	0.10	0.70
Density (g/cm³)	2.31	2.29	2.26
Graphite Content (%)	28.00	99.90	100.00
Morphology	Granular	Flaky	Layered

Table 2. Comparison of synthetic and natural graphite (MTA, 2023; IMIB, 2020)

Properties	Natural Graphite	Synthetic Graphite
Production method	Natural formation (metamorphism)	High temperature carbonization
Carbon Footprint	1–2 kg CO_2/kg	4,9 kg CO_2/kg
Purity	Low–medium	High

It is stated that the visible graphite reserves in the world are approximately 300 million metric tons, and this figure can reach 800 million metric tons with potential reserves. Turkey has 30% of the world reserves with approximately 90 million tons of reserves. However, since the graphite deposits in Türkiye are amorphous, they are imported for applications requiring high purity (IMIB, 2020; Kaya, 2006).

Finally, although various studies are carried out in the world on graphite recycling, there is no effective application in Turkey yet. Recycled graphite can be reused as brake pads, thermal insulation materials and carbon additives, which provides both economic and environmental benefits. In particular, the recovery of graphite content in lithium-ion batteries will have strategic importance in the coming years (MTA, 2023; Liu et al., 2024).

3. Applications of graphite within the scope of thermal energy management in buildings

Graphite is used as an additive in many insulation systems due to its high thermal conductivity, low emissivity and stable physical properties (Çuhadaroğlu and Kara, 2018); thus, it provides performance improvements for different heat transfer mechanisms. The effects of graphite additive on the methods developed against the three basic heat transfer mechanisms affecting thermal insulation offer a remarkable research area. In the literature, it is seen that graphite-containing materials affect these three heat transfer paths (conduction, radiation and heat storage/release (thermal mass)) in different ways. Therefore, the effects of graphite on these transition paths will be evaluated under separate headings; analyzes specific to each heat transfer mechanism will be presented according to the materials to which graphite is added. In this context, the effects of graphite additive on thermal performance will be examined on three different building material groups, namely EPS, mortars and pastes and phase change materials (PCMs). In Table 4, the heat transfer mechanisms affected by graphite, the roles it undertakes in these processes and the thermal performance changes that occur accordingly are summarized.

3.1 Effect of graphite on thermal conductivity

Graphite is a carbon allotrope with high thermal conductivity (Pierson, 1993). Therefore, it can have an effect on increasing conductivity in the materials it is used in, and this situation can vary depending on factors such as the binder matrix used, the amount of graphite, particle size and distribution homogeneity. The effects of graphite added to EPS and mortar mixtures, respectively, are as follows.

3.1.1. EPS with graphite

When micron-sized graphite particles were added to expanded polystyrene (EPS), significant decreases in thermal conductivity were observed (Blazejczyk et al., 2020; Lakatos & Csík, 2022). This decrease is explained by two main mechanisms: (i) reduction of radiative heat transfer due to the high infrared radiation absorption capacity of graphite, (ii) suppression of conductive heat transfer by interrupting the phonon conduction paths in the polymer matrix by graphite (Blazejczyk et al., 2020). Lakatos et al. (2018) measured the thermal conductivity values in the range of 0.030–0.032 W/m K in graphite-added EPS materials from five different manufacturers, and obtained results that were close to the manufacturers' data but with 5–10% deviation. These differences were attributed to graphite distribution and porosity. Blazejczyk et al. (2020) reported a 17.2% reduction in thermal conductivity in 'gray' EPS panels containing up to 7.3% graphite, compared to low-doped 'speckled' EPS; the thermal conductivity of the 'gray' panels was measured at 0.0312 W/m·K. Micro-Raman analyses showed that the phonon spectrum was suppressed and there was a deterioration in the polymer chain structure. These graphite microparticles reduce the phonon conduction of the polymer matrix, reducing heat conduction.

Table 3. Physical properties of graphite (Olson, 2020; MTA, 2023; Kaya, 2006; Pierson, 1993)

Properties	Value
Density	2.1–2.3 g/cm³
Hardness (Mohs)	1–2
Melting Point	3.927 °C
Electrical Conductivity	20 times more than copper (specific)
Thermal Conductivity	398 (W/mK)*
Specific Heat	0.690 - 0.719 (kJ/kgoK)

*For commercial pyrolytic graphite, the thermal conductivity is 390 W/m·K in the ab directions.

Table 4. Effects of graphite addition to different materials.

Material	Heat Transfer Mechanism Affected by Graphite	Role of Graphite	Performance Improvement	References
EPS	Conduction	Phonon scattering, formation of micro heat paths	15–30% reduction in thermal conductivity	Blazejczyk et al. (2020); Rydzkowski et al. (2020); Lakatos et al. (2018)
EPS	Radiation	Infrared absorption and scattering	15–25% improvement in total U-value	Rydzkowski et al. (2020); Zhou et al. (2024)
Mortar	Conduction & Thermal Mass	Microstructure densification, porosity reduction	Up to 97% increase in thermal conductivity; Increase on specific heat capacity. Reduction on thermal flux 6% -54%;	Medina et al. (2018); Barbero-Barrera (2017a), Silva & Gachet (2024)
PCM	Conduction & Thermal Mass	Acceleration of phase change, leakage prevention	0.2 → 0.48 W/m·K increase in conductivity; Increase in heat storege capacity 13.86 → 47.36 kJ	Chen et al. (2024); Belete et al. (2024); Zhang et al. (2006); Cui et al. (2015)

This shows that it has a strong effect not only on radiation but also on matrix conductivity. In addition, a non-standard experiment with aluminum foil in heat flow meter (HFM) tests was carried out by Blazejczyk et al. (2020) to measure the total thermal conductivity and separate the radiation and conduction components from each other. As a result, it was found that graphite-doped samples almost completely block the radiation, and Graphite microparticles (GMP) not only suppress the radiation but also prevent the propagation of acoustic and optical phonons by disrupting the order of the polymer chains. Phonons (heat-carrying vibrations) are strongly scattered in the boundary regions between the graphite and the polystyrene matrix, less frequently reflected, and delayed by being absorbed and scattered in random directions within the graphite. In addition, the interaction between the graphite and the polymer chains in the matrix disrupts the matrix, which slows down the heat conduction. All these processes hinder the movement of phonons, thus seriously reducing heat conduction (Blazejczyk et al., 2020). In the study conducted by Rydzkowski et al. (2020), the thermal conductivity decreased to the range of 0.024–0.025 W/m K with graphite nanoparticles added to EPS (reference EPS: 0.038–0.040 W/m K), which means a 35–40% decrease. It was stated that this improvement was due to the graphite particles being embedded in the walls of the EPS granules and limiting the radiation effect.

These studies show that graphite added to EPS not only reduces heat conduction but also increases the thermal stability and fire resistance of the structure. A summary of various studies investigating the use of graphite in EPS materials, including details such as graphite type, content, particle size, and corresponding thermal conductivity, is presented in Table 5.

3.1.2 Mortars and pastes with graphite

Studies have been conducted to research the effect of graphite on thermal conductivity by adding it to cement and lime based mortar systems. The graphite used is usually in the form of isostatic graphite powder, expanded graphite (EG) or synthetic flake and the particle size is mostly at the micron level. In the research of Medina et al. (2016), series of gypsum pastes with 0–5–10–15–20–25% of graphite filler by weight replacement of gypsum, decreased porosity and water absorption rates and increased compressive strength up to 275%. According to Medina et al. (2018), the incorporation of industrial waste isostatic graphite powders into cement pastes and mortars (as 10–30% cement replacement) resulted in an increase in thermal conductivity up to 171% despite the decrease in bulk density. This increase was paralleled by the increase in mechanical strength. It may encourage its use in conductive flooring for heating purposes and solar energy storage materials.

Barbero-Barrera et al. (2017a) studied on the gypsum-based systems, by adding 0-25%, gypsum replacement resulted in increases of up to 19% in bulk density, up to 97% in thermal conductivity and up to 10.3% in emissivity, while in radiant building applications, thermal flux was reduced by 54% towards the outside. This showed that graphite gypsum composite material is particularly suitable for use in radiant systems.

Table 5. Summary of EPS studies with graphite

Reference	Type of Graphite	Graphite Content	Graphite Particle Size (μm)	Thermal Conductivity (λ or R)
Blazejczyk, 2020	Graphite Microparticles (GMP)	Product B: low GMP Product C: high GMP	1–15 μm	λD: ~0.0305 W/m·K at 10°C
Lakatos et al., 2018	Nano/micro graphite flakes	Not specified quantitatively	Not specified	λ ≈ 0.031–0.033 W/m·K
Lakatos & Csík, 2022	Microscale & nanoscale graphite powder	Not specified quantitatively	Nano size (heat mirror effect)	λ < 0.039 W/m·K (better than white EPS)
Rydzkowski, 2020	Graphite nanoparticles	Added during granule formation	Dispersed in cell walls, <5 μm wall thickness	Best thermal conductivity among tested variants
AIA Platinum GPS	High-purity graphite (IR absorber/reflector)	<1% of total mass	Not specified	R-value: ~5.0 ft²·h·°F/BTU per inch (~0.028 W/m·K)

Barbero-Barrera et al. (2017b), in another study, tested samples containing different hydraulic lime replacements with graphite ranging from 0% to 50% and reported an increase of up to 80% in thermal conductivity. In the same study, the best results were obtained in mechanical strength with 25% graphite addition. Again, it was concluded that it became useful in high-temperature products and also in radiator floors, ceilings or walls thanks to the graphite addition. Filazi et al. (2023) studied alkali-activated mortars with 0.5–4% graphite addition and 24.6% increase in electrical conductivity was achieved with 4% addition, and no tests were performed on thermal conductivity. Silva & Gachet (2024), in their study aiming to evaluate the electrical and mechanical properties of mortars produced using Portland cement, sand and powdered graphite at 0%, 5%, 10% and 15% by mass of cement, found that electrical impedance decreased by 259.42% with 15% graphite addition, i.e. high electrical conductivity was achieved. No tests were performed on thermal conductivity.

In general, the range of 10–15% is recommended as the optimum additive ratio in terms of thermal conductivity and workability balance. In addition, when the additive ratio exceeds 25%, mechanical strength decreases and serious deterioration in workability can occur (Barrera et al., 2017b). It can be said that graphite creates conductive networks in the mortar matrix, not only increasing thermal conductivity but also providing electrical conduction, which offers great potential for smart building materials. Table 6 summarizes various studies on mortar and paste incorporating graphite, highlighting differences in binder types, graphite sources, contents, particle sizes, and reported thermal conductivity values.

3.1.3 PCMs with graphite

Phase change materials (PCM) play an important role in increasing the passive heat storage capacity for structures; however, their heat transfer rates are generally limited due to low thermal conductivity. In order to overcome this deficiency, the use of graphite additives in PCM systems has been intensively investigated in recent years. In general, graphite has been integrated into cement-based phase change material systems in different morphologies (e.g. expanded graphite, graphite sheets, microencapsulated graphite-added PCMs) in order to eliminate the problem of low thermal conductivity, accelerate heat storage and release processes, prevent possible leaks in paraffin-based PCMs through physical adsorption, and optimize both thermal and mechanical performances of building materials. In this context, graphite has functioned as both a conductivity-enhancing additive and a supporting matrix that stabilizes the phase change medium. High thermal conductivity enables composites to be used more efficiently as resistance heating elements due to the increase in heating rate; It increases the storage efficiency of paraffin, so it is desirable for heat storage capacity because the heat storage and release time is reduced (Fraç, 2021). Zhang et al. (2006) reported a 221% increase in thermal conductivity of paraffin-SBS based shape-stable PCM with 20% flake graphite addition. However, mechanical weakening and paraffin leakage were observed with additions above 15%. Zhang & Fang (2006) found that 85.6% paraffin-based PCM impregnated with expanded graphite shortened the heat storage time by 27% and the cooling time by 56% compared to conventional paraffin. Zhang et al. (2013) added 0.5–2.5% n-octradecane/expanded graphite-based PCMs to cement mortar and achieved a 8.7 °C decrease in indoor temperature, a 15% decrease in thermal conductivity, and an increase in heat storage capacity.

Table 6. Summary of mortar and paste studies with graphite

Reference	Binder	Type of Graphite	Graphite Content (%)	Graphite Particle Size (μm)	Thermal Conductivity (λ or R)
Medina et al., 2016	Gypsum	Recycled isostatic EDM graphite	5–50	1–10 (peak), 35–150 (agg.)	0.341–0.739
Barbero-Barrera et al., 2017b	Hydraulic Lime	Waste graphite powder	5–50	Not specified	0.05–0.30
Filazi et al., 2023	BFS-based AAM	Commercial graphite powder	0.5–4	≤75	Not reported
Medina et al., 2018	Portland Cement	Isostatic graphite	Up to 30	~10	Up to +171%
Barbero-Barrera et al., 2017a	Gypsum	Revalorized graphite	Not specified	Not specified	0.329–0.725
Silva & Gachet, 2024	HES Portland Cement	Commercial powdered graphite	5, 10, 15 by weight of cement	75	Not reported

Cui et al. (2015) observed a 40% decrease in thermal conductivity with 20% addition in mortar systems containing graphite-added microencapsulated paraffin (GM-MPCM). Frąc et al. (2021) incorporated expanded graphite (EG) impregnated paraffin into the cement matrix at a ratio of 10–30 wt% of cement and found that the composites exhibited a high degree of thermal conductivity despite the high paraffin content with low thermal conductivity. This high thermal conductivity was attributed to the inclusion of expanded graphite, which is characterized by this property. Xiong et al. (2022) added graphite flakes to increase the thermal conductivity of microencapsulated PCM-cement composites, aiming to improve the heat storage and release rates by forming conductive networks in the matrix. As a result, the incorporation of 5 wt% graphite powder (GP) into CP-MPCM composites increased the thermal conductivity by up to 50.1%, improved the heat storage and release rates by over 25%, and improved the overall heat storage coefficient of the cement paste by 55.8%. Chen et al. (2024) applied graphite as a coating on porous Al_2O_3 ceramic, which is widely used in PCM packaging due to its advantages of controllable porosity and high thermal conductivity. Graphite coating was used to significantly increase the very low thermal conductivity of Lauric Acid/Myristic Acid (LA/MA), a phase change material (PCM). It was increased by approximately 20.7 times by compensating for the low conductivity of Al_2O_3. Belete et al. (2024) incorporated graphite into cement-based plaster mortar as part of a shape-stable phase change material (SSPCM) together with graphite, sodium sulfate decahydrate and calcium chloride hexahydrate. Thus, the thermal conductivity of the composite increased from 2.81 to 3.86 W/m °C. Both sensible and latent heat storage capacity of PCM increased with graphite addition, and the total heat storage capacity reached from 13.86 kJ to 47.36 kJ. Table 7 provides a summary of studies on the incorporation of graphite into PCM systems, outlining their material compositions, graphite types and contents, particle sizes, and the intended functions of graphite in enhancing thermal performance.

High thermal conductivity allows composites to be used more efficiently as resistive heating elements by increasing the heating rate. It is also preferred in terms of heat storage capacity; because it increases the heat storage efficiency of paraffin and shortens both heat storage and release time (Fraç et al., 2021). These findings show that graphite acts as an active heat transfer promoter and thermal stabilizer in PCM systems, not as a passive additive. Graphite improves both the energy performance and structural integrity of PCM-containing building materials by providing both impermeability and increasing thermal conductivity. However, as the additive amount increases, the risk of loss in mechanical strength increases, and the optimum graphite additive rate remains in the range of 5–15%.

3.2 Effect of graphite on radiation

Graphite has the capacity to limit not only conductive heat transfer but also radiative heat transfer. Lakatos et al. (2018) stated that graphite has very good infrared radiation absorption and also has a radiation scattering behavior. Especially compared to traditional insulation materials with low emissivity, graphite's radiation absorption and scattering properties are remarkable. Thanks to its low emissivity, graphite is an effective additive material in limiting heat transfer by radiation.

Table 7. Summary of PCM studies with graphite

Reference	**Material Composition**	**Type of Graphite**	**Graphite Content**	**Graphite Particle Size (µm)**	**Purpose of Use of Graphite**
Reference	Material Composition	Type of Graphite	Graphite Content	Graphite Particle Size (µm)	Purpose of Use of Graphite
Zhang et al., 2006	Paraffin + SBS + additives	Exfoliated graphite	0–20 wt%	Not specified	Enhance thermal conductivity of shape-stabilized PCM
Zhang & Fang, 2006	Paraffin + Expanded Graphite (EG)	Expanded Graphite (EG)	85.6% paraffin loading, 14.4% EG	300 µm, 200 mL/g expansion ratio	Support structure and enhance heat transfer in PCM
Zhang et al., 2013	n-octadecane + EG + Cement mortar	Expanded Graphite (EG)	0.5–2.5% composite PCM in TESCM	500 µm, 300 mL/g expansion ratio	Prevent PCM leakage and improve heat storage in cement mortars
Cui et al., 2015	Paraffin + Microcapsule + Flake Graphite + Cement	Flake graphite	5–20% GM-MPCM (graphite portion not specified)	800 mesh (~20 µm)	Enhance thermal conductivity of MPCM in cement composites
Zhang, 2006	Shape-stabilized paraffin PCM + additives	Graphite	0–20 wt%	Not specified	Improve thermal conductivity of shape-stabilized PCM
Fraç et al., 2021	Cement + 20–25% EG/Paraffin composite	Expanded Graphite (EG)	20–25% (composite form)	142–168 kg/m³ bulk density	Enable self-heating and storage in electric cement composites
Bi et al., 2020	Diatomite + EG + Paraffin + Cement mortar	Expanded Graphite (EG)	1–2 vol%	d50 ≈ 505 µm	Improve water resistance and thermal storage in steam-cured mortar
Cui et al., 2015	GM-MPCM (Paraffin + Flake Graphite) + Cement mortar	Flake graphite (800 mesh)	5–20% (graphite portion in GM-MPCM not specified)	150–350 µm (GM-MPCM size)	Enhance mechanical and thermal performance in cement mortar
Belete et al. 2024	$Na_2SO_4 \cdot 10H_2O$ + $CaCl_2 \cdot 6H_2O$ + Graphite + Cement mortar	Graphite (shape-stable)	Not specified	Not specified	Stabilize PCM and improve composite thermal management

3.2.1 EPS with graphite

Lakatos & Csík (2022) stated that in graphite-doped EPS plates, nanosized graphite particles act as heat mirrors by scattering and partially reflecting infrared radiation, while graphite powders on the cell walls absorb and significantly reduce radiative heat transfer. Blazejczyk et al. (2020) stated that the addition of graphite to EPS also reduces heat transfer by radiation, but to a lesser extent than conduction. Graphite absorbs and reflects infrared radiation, which reduces radiative transfer. By integrating graphite flakes into the polystyrene matrix, thermal conductivity is reduced by graphite particles that reflect and absorb radiation energy (Nowoświat et al. 2021).

These studies reveal that graphite is an active additive material in EPS systems that also acts as a phonon reflection and radiation suppressor.

3.3 Effect of graphite on thermal mass

Thermal mass refers to the ability of a material to store heat and delay and balance ambient temperature changes. This feature is of great importance in terms of increasing indoor comfort and reducing energy consumption. Thanks to its high thermal conductivity and specific heat capacity, graphite significantly contributes to thermal mass by increasing sensible and latent heat storage capacities in various building materials.

Graphite can affect heat storage and release processes in systems where it is included as an additive. It can have an effect on the absorption and delayed release of heat, especially when used in plasters, concrete-like mixtures or PCM systems. In addition, it can provide optimizing effects on time lag depending on the distribution, density and location of graphite in the material.

The use of materials with high thermal conductivity is critical for efficient energy transfer to interior spaces. In addition, materials with high or medium specific heat capacity are needed to support energy accumulation and overall thermal stability of the system (Barbero-Barrera et al., 2017a).

3.3.1 Mortars and pastes with graphite

In mortar systems, the thermal mass value depends on density, specific heat and temperature change capacity. Graphite, in these systems, spreads heat faster thanks to its distribution in the microstructure, and also contributes to the extension of thermal balance by providing an increase in specific heat. Barbero-Barrera et al. (2017a) achieved an increase of in specific heat capacity with 25% graphite addition in gypsum-based systems, and a decrease in thermal flux of 6–54% according to simulations. This can be said to be an indirect thermal mass effect that reduces indoor temperature fluctuations.

3.3.2 PCMs with graphite

The most intensive and directly observed contribution of graphite to thermal mass is seen in PCMs. PCMs, by their nature, can store heat as sensible and latent. Adding graphite to PCMs both accelerates this storage and increases the capacity. Belete et al. (2024) increased the heat storage capacity from 13.86 kJ → 47.36 kJ in PCMs containing sodium sulfate decahydrate and calcium chloride hexahydrate with 8% graphite, increased the specific heat capacity from 0.92 → 1.33 kJ/kg °C and the diffusion coefficient from $1.40 \times 10^{-6} \rightarrow 1.68 \times 10^{-6}$ m^2/s. These data directly reveal the increase in thermal mass. Chen et al. (2024) showed that the latent heat capacity of the FSPCMs30 system was 73.93 J/g, high specific heat and low diffusivity, long-term heat retention and late release were achieved. In the study of Zhang & Fang (2006), the heat discharge time in PCM systems with EG additives was 56% shorter than in conventional paraffin; this enabled the PCM to operate in a sharper temperature range and improved energy management. Cui et al. (2015) reported that the inner surface temperature in mortar systems with GM-MPCM additives was reduced by 4.1 °C, and the formation of the heat peak was delayed by 12 minutes. This is a thermal buffering effect that directly contributes to the thermal mass. In line with these data, it was clearly demonstrated that the graphite additive significantly improved the thermal mass in PCM systems by storing heat more efficiently, releasing it later and slowing down the heat fluctuations

4. Conclusions

Within the scope of this study, the effects of graphite additive on building materials were examined through three basic heat transfer mechanisms (conduction, radiation and thermal mass); evaluations were made specifically for EPS, mortar and PCM systems. The findings are summarized under the following headings:

4.1 Effects on thermal conductivity

- In EPS systems, graphite particles provide a conductivity decrease of 15–40% by preventing phonon conduction within the polymer matrix.
- In mortar systems, especially at 10–15% additive rates, graphite formed conductive networks within the matrix and provided a thermal conductivity increase of up to 171%. However, workability and mechanical strength were weakened at additives above 25%.
- In PCM systems, thermal conductivity increased up to 221% with flake or expanded graphite additives. Especially with graphite-coated Al_2O_3 structures, a value of 3.73 W/m K was reached.

4.2 Effects on radiation

- The effect of graphite on heat conduction is twofold: It both blocks radiation (infrared absorption of graphite) and reduces phonon transmission within the matrix.
- The radiative absorption capacity of graphite in EPS and its distribution within the matrix suppressed the total heat transfer, providing low temperature stabilization and fire safety.

4.3 Effects on thermal mass

- In PCM systems, specific heat capacity, diffusion coefficient and total heat storage capacity have increased significantly with graphite addition.
- In mortar systems, especially in gypsum-based systems, increase in specific heat capacity and up to 54% decrease in thermal flux indicate that indoor temperature oscillations are balanced.

Table 8. Effects of Graphite Properties on Thermal Conductivity, Radiative Heat Transfer, and Thermal Mass in Building Materials

Material	Property Range Obtained	Thermal Conductivity Reduction	Radiative Heat Transfer Reduction	Enhancing Thermal Mass
EPS	Graphite content: <1–7.3% by weight. Particle size: Nano (<5 µm) to micro (1–15 µm). Types: Nano/micro flakes, microparticles, high-purity graphite.	15–40% reduction (λ: 0.038–0.040 W/m·K to 0.024–0.033 W/m·K). Examples: 7.3% graphite: -17.2% (λ = 0.0312 W/m·K); Nanoparticles: 35–40% reduction.	Nearly blocks radiation (HFM tests). Graphite particles scatter/reflect IR; cell wall graphite absorbs IR. Significant but secondary to conduction.	Limited impact. Indirectly improves heat retention via thermal stability.
Mortars/Pastes	Graphite content: 0.5–50% by weight. Particle size: Micro (1–75 µm). Types: Isostatic, expanded, synthetic flake, waste graphite.	Typically increases λ. Up to 171% increase in thermal conductivity.	Reduces thermal flux by 54% in radiant systems. Increases emissivity (+10.3% in gypsum). Less focus than conductivity.	Increases specific heat. Reduces thermal flux (6–54%), stabilizing temperatures.
PCMs	Graphite content: 0.5–25% by weight. Particle size: Micro (20–500 µm). Types: Expanded graphite, flakes, microencapsulated.	Often increases λ, (e.g., +221% paraffin-SBS, +50.1% CP-MPCM, +20.7x Al_2O_3-PCM, 2.81 to 3.86 W/m·K SSPCM). Exceptions: -40% (20% GM-MPCM mortar); -15% (0.5–2.5% EG-PCM). Optimal: 5–15%.	Reduces IR transfer, stabilizes PCMs (e.g., prevents paraffin leakage). Less emphasized than conductivity/thermal mass.	Boosts heat storage (e.g., 13.86 kJ to 47.36 kJ at 8% graphite). Increases specific heat. Delays heat peaks.

Table 8 summarizes the effects of graphite additives on different building materials. For EPS, mortars and phase change materials (PCM); the effects of the properties such as graphite content percentage, particle size and type on thermal conductivity (λ), radiative heat transfer and thermal mass are presented comparatively. In EPS, nano and micro sized graphite additives reduce thermal conductivity by 15–40%, while effectively reflecting infrared radiation and largely preventing radiative heat transfer. In mortars, low graphite amounts can provide a limited decrease in λ, while high amounts generally increase the λ value; however, they provide significant gains on thermal mass. In PCM systems, graphite generally increases thermal conductivity. In addition, graphite additives improve system stability by increasing thermal storage capacity and temperature compensation performance in these systems. The trends observed in thermal behaviors according to the amount and type of graphite additive for each material group are clearly presented in the table.

Graphite additive has the potential to provide an effective and sustainable solution in making building materials multifunctional. In EPS, the same thermal insulation performance is achieved with much thinner layers; PCM and mortar systems offer striking advantages in terms of heat management, energy saving and thermal comfort. However, optimization of the additive ratio is critical in terms of preserving mechanical and workability properties.

4. Further studies

The findings obtained within the scope of this study showed that the addition of graphite to building materials provides significant changes in heat conduction, a decrease in EPS and an increase in mortars, in contrast to each other; suppression of heat conduction by radiation, as in the case of EPS, and an increase in thermal mass. However, the full potential of graphite in architectural materials has not yet reached its limits. The following suggested research directions may guide future studies:

Although the effects of flake, expanded and synthetic powder graphite types in various material systems have been studied in the existing literature, a comparative evaluation of these graphite types under the same conditions has not been made. In future studies, the effects of different graphite types on heat transfer, mechanical strength and long-term stability can be examined in detail.

Graphite has been observed to affect not only thermal insulation but also properties such as electrical conductivity, fire resistance and surface emissivity. In this context, it has high potential in designing multifunctional materials, especially for applications such as smart building components, radiant heating systems and heat storage panels.

The effects of graphite-added materials on annual energy consumption, indoor thermal comfort and carbon emissions can be considered a subject worth investigating.

Although there are studies on the response of graphite to UV radiation, humidity and temperature cycles, it is not yet sufficiently understood. Especially in exterior facade applications, whether graphite materials experience a loss of performance over time can be revealed with long-term aging tests.

The environmental footprint, energy recovery potential and recyclability of end-of-life materials of graphite-added building materials should be investigated.

The high performance of graphite-added EPS panels against low thermal conductivity and radiation resistance suggests that such behaviors can be transferred to other matrix systems. Future studies may aim to develop new composite materials that mimic the microporous structure of EPS but contain cement, lime or geopolymer-based binders. In such systems, improvements in thermal insulation performance can be achieved by utilizing both graphite's ability to block radiation and create conductive paths.

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Sustainable concrete with reduced environmental impact as a building material

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Abstract. Concrete is one of the most widely used construction materials worldwide due to its durability, ease and speed of production, and design flexibility. The production of concrete requires aggregate, water, cement, and various mineral and chemical admixtures. The environmental impact of concrete is determined by multiple factors, including the extraction and production of its constituent materials, the manufacturing process, transportation to the construction site, placement into formwork, curing, usage, and end-of-life disposal. With the increasing global demand for concrete, its environmental impact has become a critical concern. Numerous scientific studies have been conducted to reduce CO2 emissions during concrete production and use, as well as to minimize raw material consumption. These studies can be classified into two main approaches: direct benefits, which involve selecting appropriate concrete compositions during the production phase, and indirect benefits, which focus on the potential reductions in CO2 emissions throughout the service life of concrete. The primary goal of these studies is to mitigate CO2 emissions associated with concrete production and utilization. This study provides a comprehensive review of global research and advancements in the production and application of sustainable concrete with reduced environmental impact as a building material. It also discusses relevant practical implementations that align with these developments.

Keywords: Concrete; Sustainable concrete; Environmental impact of concrete

1. Introduction

Concrete is defined as a composite construction material produced by homogeneously mixing cement, water, aggregates, and admixtures in specified proportions. Initially exhibiting a plastic consistency, it hardens through the process of cement hydration and solidifies by taking the shape of the formwork in which it is placed.

Among all construction materials, concrete is the most widely produced and used within the building industry. It stands out due to its cost-effectiveness, the ability to achieve the required compressive strength, long service life, and ease of production.

The fact that concrete production mainly relies on raw materials such as cement, aggregates, water, and chemical or mineral admixtures indicates a high level of natural resource consumption. Furthermore, it is well known that the concrete production industry has a significant carbon footprint (Scrivener, 2018).

The construction sector is responsible for a considerable portion of global greenhouse gas emissions. Concrete production, in particular, is subject to criticism due to its high energy demand and CO2 emissions, which pose challenges in terms of environmental sustainability goals. As a result, various alternative solutions have been developed (Arıoğlu etal, 2004).

In this context, the concepts of low-impact concrete, green concrete, and sustainable concrete have emerged. Within the construction industry, the notion of sustainability must be addressed through environmental, economic, and social dimensions. Various criteria have been established for assessing sustainability based on these dimensions. The sustainability criteria formulated for building materials are outlined below.

Sustainable building materials are those that consume minimal energy during their service life and do not pose harm to the environment or human health throughout the stages of raw material extraction, processing, usage, maintenance, or disposal. Also referred to as "green" materials, sustainable building materials are produced in a way that minimizes environmental damage and utilizes non-renewable resources responsibly and efficiently.

In the selection of building materials, alongside conventional criteria such as performance, quality, aesthetics, and cost, compliance with sustainability principles is also expected.

Sustainable materials are characterized by the following features (Tufan & Özel, 2018) (Table 1):

- They do not contain toxic components and therefore are not harmful to human health.

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- They are recyclable or reusable.
- They do not adversely affect the natural environment after their functional life ends.
- They are sourced from local materials and producers.

Table 1.Sustainability criterias (Tufan and Özel, 2018)

Sustainability Dimension	Criteria
Environmental Dimension	Is there a reduction in waste?
	Can air pollution be prevented?
	Is the produced material toxic to the environment?
	Does it reduce CO_2 emissions?
	Does it help preserve biodiversity in nature?
	Is the material harmful to soil quality?
	Can it absorb odors from the environment?
	Is the material recyclable?
	Does it have high reusability potential?
	Does it help prevent visual pollution?
	Does it help prevent noise pollution?
	Is the energy consumption low?
	Can it be sourced from local and natural resources?
	Can water pollution be prevented?
Economic Dimension	Is it possible to reduce energy consumption during raw material transport?
	Can transportation costs be minimized?
	Is maintenance and repair easy?
	Is the material durable and long-lasting?
	Does it reduce material use in the provision of goods and services?
Social Dimension	Is the material compatible with the social fabric of the region?
	Does it promote a healthy environment?
	Does it ensure safety for human use?
	Does it meet the housing needs of people?
	Does it support social needs such as education, cultural activities, appropriate jobs and housing?
	Does it support the local workforce?

2. Materials and methods

This study conducted a literature-based review using articles, technical reports and international case studies. The sources are categorized into two main sections:

- Direct reductions in CO2 emissions through material substitutions and low-clinker cement production.
- Indirect reductions through improved durability, maintenance strategies and smart use of concrete in energy-efficient buildings (Orhon, 2012).

2.1. Direct benefit approaches

Direct benefit approaches refer to sustainability strategies aimed at reducing CO2 emissions during the concrete production process. A key concept in these approaches is "embodied CO2", which represents the amount of CO2 emitted into the atmosphere during the manufacturing of construction materials. This term is derived from "embodied energy," which describes the energy consumed during production, and is adapted to reflect CO2 emissions. It is often abbreviated as EC or ECO2 (Embodied CO2).

To reduce the ECO2 value of concrete, sustainability strategies during the production phase include the selection of appropriate constituents and optimized concrete mix design.

Cement production ranks third among global anthropogenic sources of carbon dioxide (CO2) emissions. Therefore, to produce more innovative and sustainable concrete, one or more of the following strategies should be employed:

1. Replacing a higher portion of cement with supplementary cementitious materials (SCMs) such as mineral additives in the concrete mix.
2. Improving concrete strength and durability by substituting cement with combinations of mineral additives.
3. Reducing the amount of cement by using water-reducing admixtures.

4. Utilizing reactive local aggregates in place of non-reactive aggregates sourced from distant locations by applying suitable binder combinations, even in cases where the aggregates may be sensitive to alkali-silica reactions.

5. Producing concrete with locally sourced crushed stone aggregates to reduce transport-related emissions and enhance material efficiency (Justnes and Martius-Hammer, 2016).

Concrete with High Volume Mineral Additions: The most effective and rapid method for reducing CO2 emissions generated during cement and concrete production is to partially replace cement in concrete with mineral additives or to use blended cement where a portion of clinker is substituted with these additives(Özcan and Güngör).

Typical mineral additives include pozzolans that react with calcium hydroxide, such as ground granulated blast furnace slag and fly ash, both of which have latent hydraulic properties. Pozzolans can also be used in combination with other materials like silica fume, rice husk ash, and metakaolin. Due to the relatively high cost of using these additives in quantities sufficient to significantly reduce CO2 emissions, research on alternative materials is ongoing.

Concrete with Low Binder Content: Limestone is a widely available natural material used both as a raw material in clinker production and as a filler in cement or concrete. Fly ash, a by-product of coal-fired thermal power plants, is available in large quantities in many countries, including China and India. The synergistic chemical interaction resulting from the combined use of fly ash and finely ground limestone can enhance compressive strength (Brito and Kurda, 2021).

The theoretical basis for this synergy is built upon a delicate balance among ettringite, monosulfoaluminate hydrate, and calcium monocarboaluminate hydrate. This balance improves water-binding capacity by enhancing hydration. Since conventional cement does not provide enough aluminates to maintain this balance, the additional aluminates from supplementary materials like fly ash are required. Thus, a ternary binder system using cement, ground limestone, and fly ash can be formed.

Use of Water-Reducing Admixtures: Many concrete producers utilize water-reducing chemical admixtures to reduce cement content for economic reasons, while also achieving environmental benefits in terms of sustainability. According to a practical standard, 1 kg of modern polycarboxylate-based water-reducing admixture can reduce the water content of 1 m^3 of concrete by 20 kg.

For instance, in a concrete mix containing 350 kg of cement and 1.8 kg of polycarboxylate admixture per m^3 with a water-to-cement ratio of 0.6, the cement content can be reduced to 290 kg while maintaining the same performance (Justnes and Martius-Hammer, 2016).

Alkali-Silica Reaction (ASR) Resistant Concrete: Silica fume (microsilica), either added directly to the concrete mix or found in the cement, reacts with hydration products to rapidly transform alkali hydroxides into silicate phases. This mitigates the risk of alkali-silica reactions. Through such methods, it becomes possible to use local aggregates instead of sourcing high-quality aggregates from distant regions, thereby promoting a more sustainable solution by extending the availability of local resources.

Locally Produced Aggregates: The depletion of traditional aggregate sources, such as natural sand and gravel, increases the need for alternative sources and technologies. Norway has taken steps in this direction by producing aggregates from hard rocks through crushing.

Sustainability in the context of aggregate access and processing presents challenges, particularly for industries managing large stockpiles of non-saleable fines (process dust).

Key principles include resource efficiency, zero waste production, recycling, and effective logistics. While manufactured sand and aggregate may require more energy than natural or untreated aggregates, when sourced close to markets, the reduction in transport emissions makes them more environmentally favorable.

Selection of Appropriate Constituents: Selecting appropriate concrete constituents is a viable strategy to reduce the embodied CO2 of concrete. Cement is a particularly strategic component due to its high embodied CO2 resulting from intense energy use and chemical processes during production. For example, 1 ton of cement production results in approximately 1 ton of CO2 emissions.

A key strategy for reducing the ECO2 of concrete is to incorporate industrial by-product pozzolans such as fly ash, silica fume, ground granulated blast furnace slag, rice husk ash, and metakaolin. As these materials are typically industrial residues with no direct application but display pozzolanic activity, they can be used both in blended cement and to partially replace cement in concrete mixes.

Due to their low embodied CO2 as by-products, their inclusion in concrete effectively lowers the overall embodied CO2 of the mix.

2.2. Indirect benefit approaches

Indirect benefit approaches aim to reduce CO2 emissions associated with the operational phase of a structure by ensuring that concrete is used in a way that leverages its inherent properties. Key characteristics to consider include durability, thermal mass, use of recycled materials, and photocatalytic functionality (Kuloğlu Yüksel and Karagüler, 2017).

From a sustainability perspective, the most effective solution is one that optimally aligns material properties with the various stages of a building's life cycle. Beginning at the design stage, the adoption of energy-efficient architectural approaches and careful selection of materials can lead to more sustainable outcomes across the entire lifespan of a building. This contributes not only to the preservation of the built and natural environment but also ensures the continued availability of finite resources.

Thermal storage capacity: In indirect benefit approaches, the key point is that concrete has a high thermal storage capacity. In other words, by using the "thermal mass" of concrete—especially in structural elements like reinforced concrete slabs—it is possible to reduce the need for heating and cooling during the building's use phase, leading to energy savings. In addition to passive solar energy applications—such as the use of Trombe walls—various active strategies are also commonly employed today to harness the thermal mass of concrete and reinforced concrete structural elements. These include techniques such as night-time ventilation and heat transfer through water circulating in facade-integrated systems for heating or cooling. In such approaches, the thermal mass of the structure is managed and optimized through building automation systems (BAS) equipped with dynamic components, enabling more efficient energy control and indoor thermal comfort throughout the building's operational phase (Orhon, 2012).

Photocatalytic properties: Concrete is a versatile material whose properties can vary significantly depending on the characteristics of its constituent materials. Among these advanced properties, photocatalytic activity is of particular interest in the context of sustainability and environmental performance. For instance, when cement containing titanium dioxide (TiO_2) is used in concrete production, the resulting material exhibits photocatalytic behavior.

Titanium dioxide, a semiconductor material, enables the concrete surface to initiate oxidation reactions under exposure to ultraviolet (UV) light. These reactions facilitate the breakdown of airborne pollutants such as nitrogen oxides (NO_x), volatile organic compounds (VOCs), and other harmful substances. Consequently, photocatalytic concrete contributes to improved air quality in urban environments.

In addition to its environmental benefits, this type of concrete also offers self-cleaning capabilities, as the photocatalytic reactions help decompose organic materials on the surface, reducing the need for maintenance and cleaning. As such, photocatalytic concrete is increasingly considered a promising innovation in the development of sustainable and smart construction materials (Kuloğlu Yüksel and Karagüler, 2017).

3. Results and discussion

This section synthesizes the findings from both the literature and case studies concerning the environmental performance of sustainable concrete technologies. The results are presented in two major categories aligned with the methodology: direct CO_2 reduction strategies and indirect CO_2 mitigation approaches.

3.1. Direct strategies

- The incorporation of supplementary cementitious materials (SCMs) such as fly ash, slag, and silica fume led to measurable reductions in clinker content and associated CO_2 emissions.
- The use of low-binder concrete mixes and water-reducing admixtures improved resource efficiency without compromising strength.
- Case studies demonstrated that localized aggregate sourcing not only reduced transportation emissions but also contributed to a circular material economy.

3.2. Indirect strategies

- Concrete's thermal mass was effectively utilized in passive design systems (e.g., Trombe walls), reducing energy loads for heating and cooling.
- Active control of thermal mass through building automation systems (BAS), including nighttime ventilation and facade-integrated hydronic systems, resulted in enhanced operational energy performance.
- The application of photocatalytic concrete was found to support air purification and self-cleaning surfaces, contributing to long-term sustainability.

These findings underscore the multifaceted role of sustainable concrete not only as a structural material but also as a tool for climate-responsive architecture. The integration of both material innovations and performance-based design enables a comprehensive reduction in environmental impact across the building life cycle.

4. Conclusions

The environmental impact of concrete is increasingly under scrutiny as the global demand for construction materials grows. While concrete remains essential for infrastructure development, its production and usage must evolve to align with sustainability goals. Direct reduction strategies, such as using SCMs and reducing clinker content, offer immediate improvements in CO_2 performance. Indirect strategies like enhancing durability and incorporating recycled materials contribute to long-term environmental benefits throughout the structure's life cycle.

Moreover, the emergence of self-healing concrete technologies represents a promising innovation in enhancing the durability and service life of concrete structures, thereby contributing significantly to long-term sustainability goals in the construction industry.

The integration of these approaches, supported by scientific research and field implementations, marks a significant step toward a low-carbon construction industry. Future work should focus on regional material optimization, life-cycle assessment tools, and policy frameworks that support greener concrete practices (Arkitera, 2025).

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Green building evaluation in historical buildings: The case of Sveti Stefan Church (Bulgarian Church)

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Abstract. The increase in energy consumption today has also influenced architecture. Factors such as the materials used in buildings, the planning and layout of structures, the impact of environmental conditions, geography, and the social context are all parameters affecting energy use. In light of the energy consumption of buildings, studies have been developed to reduce energy demand, leading to the emergence of concepts such as 'sustainable architecture' and 'green building.' Within this framework, new strategies and methods have been introduced to align with sustainable architecture and green building practices.
Historical buildings are also crucial to consider within the scope of sustainability. As cultural heritage assets, these buildings should be preserved and transferred to future generations. From this perspective, historical structures should also be evaluated in terms of sustainable architecture and green building certification systems.
The Sveti Stefan Church is the world's only 'fully prefabricated iron church,' making it unique and noteworthy. This study aims to evaluate the Sveti Stefan Church through the lens of sustainable architecture and green building certification systems. A new Green Building Evaluation Model will be developed for the historical structure, and the building will be assessed using this model. In this context, the evaluation will focus on parameters such as the materials used, the planning and layout of the building, the impact of environmental factors, and the geographical and social context.

Keywords: Sustainable Architecture; Green Building Evaluation Systems; Historical Buildings; Sveti Stefan Church.

1. Introduction

The energy performance of buildings is shaped by a range of factors, such as material selection, architectural planning and spatial organization, environmental conditions, geographic setting, and socio-cultural context. In recent decades, there has been a marked increase in energy consumption, a trend that has become increasingly evident within architectural practice. This growing concern has led to the development of strategies focused on energy efficiency, ultimately giving rise to the concept of sustainable architecture. Within this framework, numerous methods and design approaches have been introduced, contributing to the evolution of "green buildings."

Green buildings refer to architectural designs that seek to minimize energy usage and maximize the efficiency of natural resource utilization. Many nations have implemented certification frameworks to promote sustainable building practices. Among the most prominent of these are BREEAM, LEED, Green Star, SB-Tool, and CASBEE.

This study proposes a novel Green Building Assessment Model tailored for historic buildings, with the aim of evaluating them through the lens of green building standards. The case study selected for this research is the Sveti Stefan Church.

As the world's only fully prefabricated iron church, the Sveti Stefan Church holds significant architectural and historical value. In this research, the church is analyzed in line with sustainable design principles and established green certification criteria. Based on the evaluation outcomes, a set of recommendations is presented to enhance the building's environmental performance.

Drawing from internationally recognized green building assessment frameworks and building upon the model introduced in Elif Gizem Yetkin's 2020 study, this research develops a tailored evaluation tool for historic structures. The proposed model aims to contribute to the sustainability and preservation of heritage buildings by identifying strategies for their improvement.

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2. Historical and Architectural Background of Sveti Stefan Church

The Sveti Stefan Bulgarian Orthodox Church, also known as the Iron Church, is the only fully prefabricated iron church in the world that has survived to the present day. It is situated between the Fener and Balat districts of Istanbul. The church was designed with a lightweight skeleton, and its components were manufactured in Vienna under the technological conditions of the period, with final assembly carried out in Balat. Due to its unique prefabricated structure, the Sveti Stefan Church was selected for analysis in this study. This section presents basic information about the church and carries out a green building assessment.

2.1. Construction and Architectural Features

The church is constructed on a stone base with a 210 cm-high masonry basement (Fig. 3), which is placed on wooden piles, and a steel column-beam system is built above it. The steel structure (Fig. 2) consists of a truss system, which is covered with cast elements on the exterior and flat sheet metal on the interior. The relief-decorated panels used in the façade are made of cast iron. Accessory profiles are mounted to the frame with rivets, while the sheet metal and cast iron panels are welded to it. The exterior walls are painted with oil-based paint, whereas the interior walls of the ground floor, along with the plastered surfaces and square-sectioned columns, are clad with marble panels in green, beige, and cherry-red colours (Çiçekliyurt, 2020).

Due to the unstable ground conditions, a steel-framed structure was proposed, and architect Aznavur designed the internal load-bearing system in 1892. The current plan of the Iron Church (Fig. 1) was developed by the Waagner company, following modifications to the load-bearing structure and decorative elements. The company initially assembled the structure in its own garden to identify and address any potential construction errors (Çiçekliyurt, 2020).

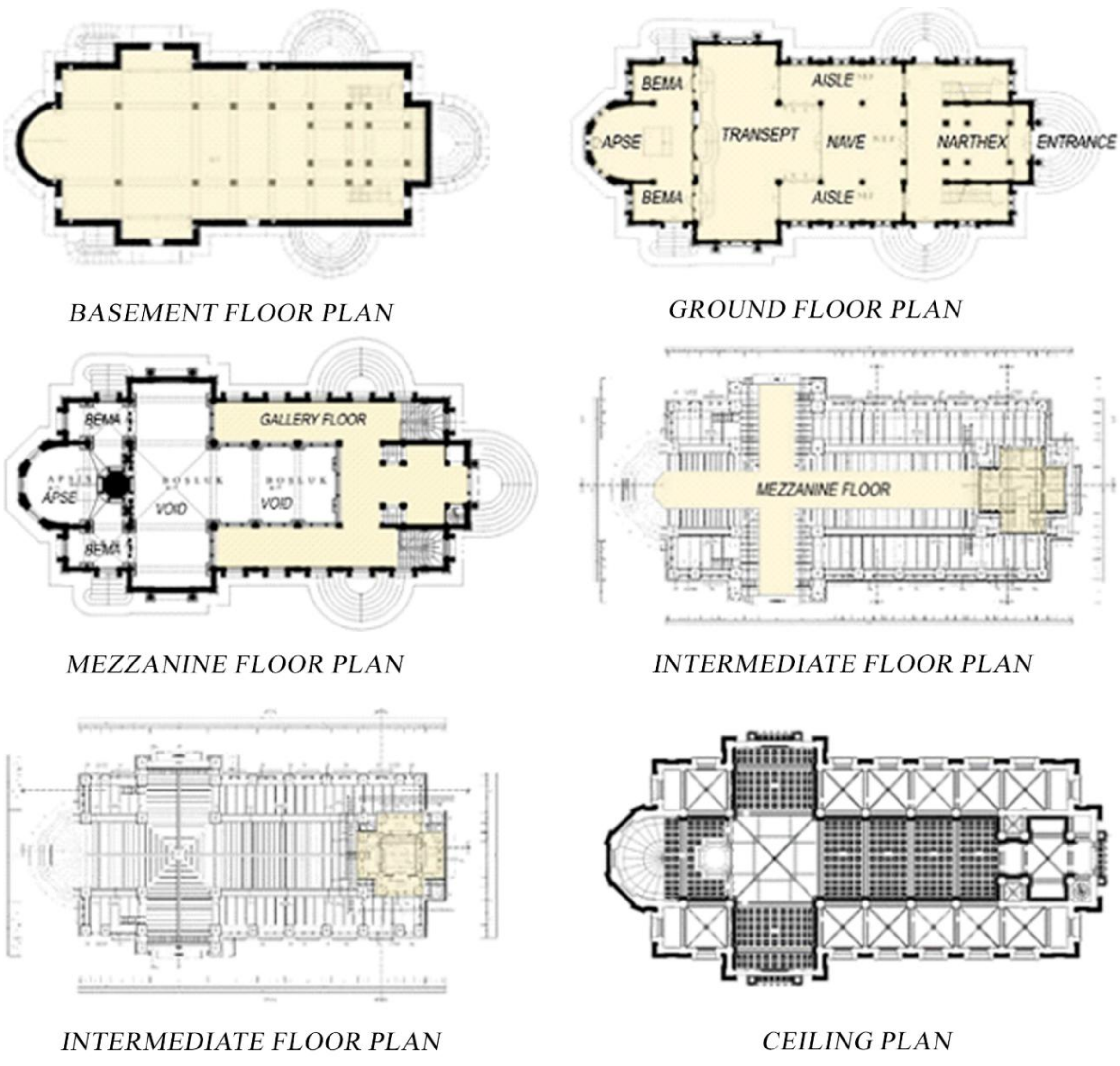

Fig. 1. Floor Plans of Sveti Stefan Church (Iron Church) (Created by editing the visuals obtained from Halil Onur Architecture.)

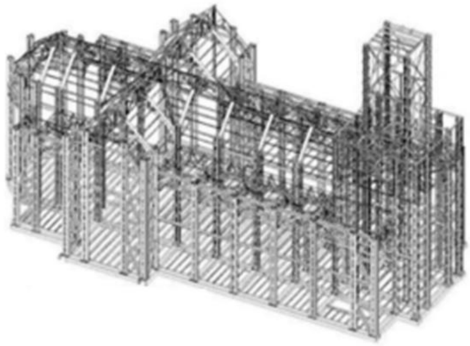

Fig. 2. The iron skeleton designed by architect Aznavur (Çiçekliyurt, 2020).

Fig. 3. Basement floor

2.2 Historical Significance
In 1849, Bulgarian Prince Stefan Bogoridi, an Ottoman State official, donated the land on which the church stands today for the needs of the church. On 17 October 1849, a special decree was issued allowing Bulgarians to have their own churches. On 9 October 1849, a small church was officially built. Later, the church was expanded and became the independent church known today as the Wooden Church (**Hata! Başvuru kaynağı bulunamadı.**). Due to damage sustained from numerous fires, permission was granted to build a new church. The project for the church, proposed to be constructed using prefabricated panels due to the unstable ground, was selected through a competition. Following the competition, it was decided to implement the design by Architect Aznavur. The assembly of the church was completed on 14 July 1896 (Bujaşka, 2016).

Fig. 4. Timber Church (Kuruyazıcı & Tapan, 2019)

3. Green Building Principles and Their Adaptation to Historical Structures
The rapid growth of technology and population during the Industrial Revolution disrupted the balance between the natural and built environments, resulting in significant damage to the natural ecosystem. Environmental degradation leads to the depletion of energy resources and creates increasingly challenging living conditions. In response to these threats, the concept of "sustainability" emerged as a preventive approach.

Global warming, climate change, pollution, and the depletion of water and energy resources—factors that mutually reinforce one another—have evolved into common challenges that transcend national boundaries. In short, human activities and their consequences are placing increasing pressure on the Earth's carrying capacity (Sev, 2009).

The construction and building sector creates the built environment. The built environment affects and degrades the natural environment. The concept of sustainable architecture emerged to mitigate this damage and to ensure that resources are preserved for future generations.

The objectives of sustainable architecture are:

- To reduce the carbon footprint
- To meet basic human needs by enhancing psychological and physical well-being and contributing positively to the social environment

Sustainable architecture is based on three fundamental principles

- Conservation of Energy and Natural Resources
- Building Life Cycle Design
- Biological Building Design (Osmançelebioğlu, 2015)

3.1. Sustainability in Heritage Conservation

The environment evolves from simplicity to complexity, creating variations based on cultural development. The environment is born, grows, develops, and diversifies through experience. During this process of development and diversification, urban elements create remnants and traces of cultural structures (Yılmaz, 1992). "These traces symbolize the economic, social, and cultural characteristics of societies, thereby forming the historical environment." (Çelimli, 2022)

Historical structures are key elements for understanding the social, cultural, and technological developments of a society. Conservation efforts are conducted to ensure that these structures are preserved for future generations. Following conservation, some structures maintain their original function, while others are repurposed. Today, environmentally sensitive and sustainable conservation practices ensure the preservation of the values of historical structures. (Eldek, 2014).

3.2. Challenges in Applying Green Building Standards

There are several established reasons for the limited implementation of green building strategies today. These factors create significant obstacles to the widespread adoption of green building practices. Some of these obstacles include:

- High cost of available products,
- Insufficient policy implementation efforts,
- Technical challenges during the implementation process,
- Lengthy planning and approval processes in green building certification systems,
- Lack of information and awareness regarding green building certification systems,
- Increased costs driven by customer demand,
- Delays caused by unfamiliarity with green technologies,
- Conflicts of interest among stakeholders (Zhang, X., Shen, & Wu, 2010).

4. Methodology for Green Building Evaluation

Green buildings are a product of sustainable architecture, which emerged alongside the concept of sustainability. Sustainable architecture aims to meet criteria such as compatibility with the building’s surroundings, the sustainability of functions, the use of renewable energy sources, energy efficiency, energy conversion, and material recycling. As a result of these criteria, green buildings emerge as structures that reduce carbon emissions, show respect for both the built and natural environments, and ensure the sustainability of the building life cycle.

Some benefits provided by green buildings include:

- Reduced energy consumption.
- Protection of ecosystems.
- Improvement in user health.
- Increased efficiency.
- Reduction in greenhouse gas emissions.
- Conservation of resources.
- Lower building operating costs (Osmançelebioğlu, 2015).

Green building assessment systems originated in the United Kingdom with the BREEAM Certification. Over time, numerous additional systems have been developed, contributing to the global growth of green buildings and the reduction of carbon emissions.

4.1. Evaluation Criteria

Green building certification systems and assessment practices were established by various countries following the identification of the need for concrete assessment and rating of green buildings through academic and sectoral studies. Today, numerous green building assessment systems have been developed and are used worldwide (Fowler & Rauch, 2006).

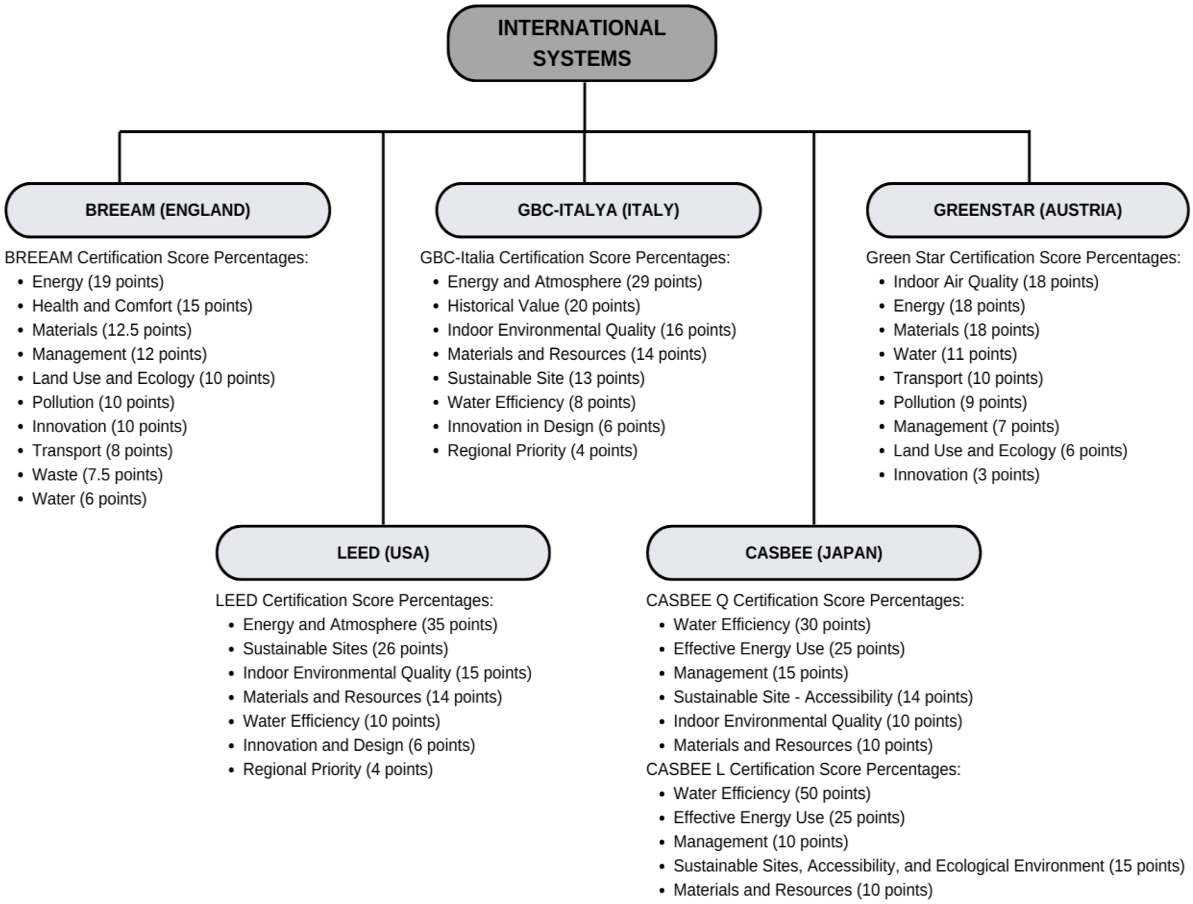

Fig. 5. International Systems (Modified from Yılmaz (2012) and rearranged by the author)

"Some of the certification systems recognized by countries that are members of the World Green Building Council (WGBC) include:

- United Kingdom - BREEAM: Developed to establish design standards, technical specifications, construction-operation phases, and building performance criteria (Global, 2016).
- United States – LEED: The LEED Certification System aims to raise awareness of environmental impacts throughout the building life cycle and improve the performance of stakeholders in the building sector (Sev & Canbay, 2009).
- Italy – GBC-ITALIA: GBC-Italia was developed based on the LEED certification and has been specifically adapted to focus on historic buildings. Buildings eligible for certification must have been constructed before the industrialization of construction (1945). This system establishes assessment guidelines tailored to Italy (Yetkin, 2020).
- Australia – GREEN STAR: Established in 2003 by the Green Building Council of Australia (GBCA), it was designed to evaluate the building life cycle, similar to BREEAM (Osmançelebioğlu, 2015).
- Japan – CASBEE: This system evaluates building design, construction, post-construction monitoring, and maintenance practices. CASBEE is more complex than other systems, with its assessment based on the formula: BEE (Building Environmental Efficiency) = Q (Built Environmental Quality) + L (Built Environmental Load) (Dullinja, 2017).
- Canada – LEED CANADA
- Germany – DGNB" (Yılmaz B. , 2012). (Fig. 5**Hata! Başvuru kaynağı bulunamadı.**)

4.2. Data Collection and Analysis

As a result of research conducted within the scope of sustainable architecture, a new evaluation system has been developed, drawing on the GBC-ITALY Green Building Evaluation System. The doctoral thesis titled "Proposal for a Green Building Evaluation Model for Historical Buildings in Our Country in the Context of Sustainable Architecture" by Elif Gizem Yetkin (2020) served as a reference in the creation of this new evaluation model.

The eight categories from the GBC-ITALY Green Building Evaluation System have been retained as main headings, with modifications made to their criteria (Table 1). The historical nature of the structure being evaluated is the most significant factor influencing the evaluation criteria. Additionally, the relationship between the structures and their sites is considered essential in maintaining the integrity of the building’s usage. It is crucial to incorporate these changes in the evaluation as technology continues to develop and evolve. In light of this, it is deemed necessary to include these factors among the criteria.

Table 1. Criteria of a Green Building Assessment System Model for Historical Buildings

Energy and Atmosphere Category Criteria
Criterion 1: Commissioning of energy systems
Criterion 2: Minimum energy performance
Criterion 3: Optimisation of energy performance
Criterion 4: Use of renewable energy
Historical Value Category Criteria
Criterion 1: Energy use assessment of existing conditions
Criterion 2: Diagnostic assessment and structural monitoring of the building
Criterion 3: Reversibility of conservation measures
Criterion 4: Assessment of conservation measures
Criterion 5: Ensuring the sustainability of the conservation area
Criterion 6: Preparation of a maintenance plan
Criterion 7: Compatibility of architectural and landscape works with the structure
Criterion 8: Functionality of the structure
Criterion 9: Relationship between the structure and the land
Interior Environment Quality Category Criteria
Criterion 1: Minimum performance for air quality
Criterion 2: Environmental control of tobacco smoke
Criterion 3: Monitoring of indoor air
Criterion 4: Evaluation of minimum outdoor air supply
Criterion 5: Indoor air quality management plan
Criterion 6: Selection of low-emission materials
Criterion 7: Control of indoor air pollutants and chemical sources
Criterion 8: Management and control of systems
Criterion 9: Ensuring spatial hierarchy
Material and Resource Category Criteria
Criterion 1: Collection and storage of recyclable materials
Criterion 2: Management of demolition and construction waste
Criterion 3: Maintenance of carrier systems and non-structural elements
Criterion 4: Use of recycled materials
Criterion 5: Optimisation of the environmental impact of materials used
Criterion 6: Materials extracted, processed and produced within a limited distance
Criterion 7: Reuse of the building
Sustainable Area Category Criteria
Criterion 1: Prevention of pollution from construction site activities
Criterion 2: Reclamation and improvement of used land
Criterion 3: Transportation
Criterion 4: Recovery of open spaces
Criterion 5: Rainwater: quantity and quality control
Criterion 6: Heat island effect: exterior surfaces and roofs
Criterion 7: Reduction of light pollution
Water Efficiency Category Criteria
Criterion 1: Reduction of water consumption
Criterion 2: Reduction of landscape water consumption
Criterion 3: Measurability of water consumption
Criterion 4: Rainwater utilisation systems
Innovation in Design Category Criteria
Criterion 1: Innovation in application
Criterion 2: Innovation in materials
Regional Priority
Criterion 1: The area has regional priority

According to Yetkin, historical structures are evaluated across three categories. Based on Yetkin's example, the point distribution for each category was analyzed according to the importance levels outlined in Table 2, leading to the creation of a new point distribution (Table 3, Table 4).

Table 2. Score Distribution by Categories in the Green Building Assessment Model for Historical Buildings (According to Yetkin)

Evaluation Categories	1st Class	2nd Class	3rd Class
Regional Priority	7	3	2
Energy and Atmosphere	17	32	40
Indoor Air Quality	11	21	18
Materials and Resources	20	13	10
Health and Safety	3	3	3
Water Management	4	4	8
Sustainable Land	4	4	6
Historical Value	30	16	9
Innovation in Design	4	4	4
Total	**100**	**100**	**100**

Table 3. Category-Based Score Distribution in the Green Building Assessment Model for Historical Buildings (According to the Developed Model)

Evaluation Categories	1st Class	2nd Class	3rd Class
Regional Priority	7	3	2
Energy and Atmosphere	17	34	42
Indoor Air Quality	11	22	19
Materials and Resources	21	13	10
Water Management	4	4	8
Sustainable Land	4	4	6
Historical Value	32	16	9
Innovation in Design	4	4	4
Total	**100**	**100**	**100**

Table 4. Score Distribution by Sub-Criteria of Categories in the Green Building Assessment Model for Historical Buildings (According to the Developed Model)

Energy and Atmosphere Category Criteria	1st Class	2nd Class	3rd Class
Criterion 1: Commissioning of energy systems	9	7	2
Criterion 2: Minimum energy performance	2	3	5
Criterion 3: Optimisation of energy performance	2	3	2
Criterion 4: Use of renewable energy	4	21	33
Historical Value Category Criteria	**1st Class**	**2nd Class**	**3rd Class**
Criterion 1: Energy use assessment of existing conditions	4	2	1
Criterion 2: Diagnostic assessment and structural monitoring of the building	9	2	1
Criterion 3: Reversibility of conservation measures	4	2	1
Criterion 4: Assessment of conservation measures	5	2	1
Criterion 5: Ensuring the sustainability of the conservation area	2	1	1
Criterion 6: Preparation of a maintenance plan	3	3	1
Criterion 7: Compatibility of architectural and landscape works with the structure	3	2	1
Criterion 8: Functionality of the structure	1	1	1
Criterion 9: Relationship between the structure and the land	1	1	1
Interior Environment Quality Category Criteria	**1st Class**	**2nd Class**	**3rd Class**
Criterion 1: Minimum performance for air quality	0	1	1
Criterion 2: Environmental control of tobacco smoke	1	1	2
Criterion 3: Monitoring of indoor air	1	1	3
Criterion 4: Evaluation of minimum outdoor air supply	1	1	0
Criterion 5: Indoor air quality management plan	0	1	1
Criterion 6: Selection of low-emission materials	3	6	4
Criterion 7: Control of indoor air pollutants and chemical sources	3	8	5
Continuation of Table 5			
Criterion 8: Management and control of systems	0	1	1
Criterion 9: Ensuring spatial hierarchy	2	2	2

Table 4. continued

Material and Resource Category Criteria	1st Class	2nd Class	3rd Class
Criterion 1: Collection and storage of recyclable materials	1	1	1
Criterion 2: Management of demolition and construction waste	0	0	1
Criterion 3: Maintenance of carrier systems and non-structural elements	4	1	1
Criterion 4: Use of recycled materials	1	2	1
Criterion 5: Optimisation of the environmental impact of materials used	4	4	3
Criterion 6: Materials extracted, processed and produced within a limited distance	1	2	1
Criterion 7: Reuse of the building	10	3	2
Sustainable Area Category Criteria	**1st Class**	**2nd Class**	**3rd Class**
Criterion 1: Prevention of pollution from construction site activities	1	1	0
Criterion 2: Reclamation and improvement of used land	0	0	0
Criterion 3: Transportation	0	0	0
Criterion 4: Recovery of open spaces	0	0	0
Criterion 5: Rainwater: quantity and quality control	1	1	1
Criterion 6: Heat island effect: exterior surfaces and roofs	1	1	5
Criterion 7: Reduction of light pollution	1	1	0
Water Efficiency Category Criteria	**1st Class**	**2nd Class**	**3rd Class**
Criterion 1: Reduction of water consumption	1	1	4
Criterion 2: Reduction of landscape water consumption	1	2	3
Criterion 3: Measurability of water consumption	1	0	0
Criterion 4: Rainwater utilisation systems	1	1	1
Innovation in Design Category Criteria	**1st Class**	**2nd Class**	**3rd Class**
Criterion 1: Innovation in application	3	3	3
Criterion 2: Innovation in materials	1	1	1
Regional Priority	**1st Class**	**2nd Class**	**3rd Class**
Criterion 1: The area has regional priority	7	3	2

Table 5. Certification Types and Scoring Methodology

Certificate Type	Point
One Star	40-49
Two Stars	50-59
Three Stars	60-79
Four Stars	80 and above

As a result of the developed scoring system, the certificate types and their corresponding scores (Table 5) are provided for the evaluation of the structure.

5. Assessment of Sveti Stefan Church in Terms of Green Building Criteria

The Sveti Stefan Bulgarian Church is analyzed and scored according to a table developed based on Yetkin's (2020) study. In the model evaluation, it is classified as a first-class structure due to its materials and construction technique.

5.1. Energy Efficiency and Renewable Energy Use

There are no energy-saving or renewable energy initiatives in the historical development or current use of the structure. Therefore, it has not been scored in the evaluation.

5.2. Historical Value

The structure continues to function in its current state through restoration work conducted in accordance with conservation criteria for historical buildings and their surroundings. The church, built on filled ground, has been lightened using iron structural elements, thereby establishing a relationship between the building and its land. The iron structural elements and the church's foundation are continuously monitored, and restoration work is carried out when damage is detected. The building receives 20 points in the current evaluation based on the following criteria: ensuring the building’s active use, preserving its function, extending its lifespan through restoration techniques, conducting structural analysis and monitoring, ensuring the reversibility of conservation efforts, evaluating the conservation process, maintaining functionality, and ensuring the relationship between the building and the land is maintained.

5.3. Indoor Environmental Quality

Due to its religious nature, there is a there is a spatial hierarchy between the spaces. Spatial orientation, varying floor heights, gallery spaces, and both interior and façade decorations contribute to this spatial hierarchy. While the presence of a spatial hierarchy earns the structure 2 points, the lack of studies addressing indoor air quality highlights a shortcoming in the evaluation criteria.

5.4. Material Sustainability and Conservation Techniques

The iron used throughout the structure is environmentally friendly because it is recyclable. As an environmentally friendly material, it also contributes to social and economic sustainability. The building's reuse includes its restoration and continued use for its original purpose. The church continues to serve its original function. The church received 14 points in the materials and resources category.

5.5. Sustainable Area

Light pollution is minimized due to the building's function. Natural lighting is essential. The building receives 1 point for this criterion.

5.6. Water Efficiency and Management

There are no studies on water efficiency or sustainability in the structure.

5.7. Inovation in Design

The use of iron materials, iron throughout the entire structure, prefabricated construction, and, consequently, new construction techniques have led to innovation in both application and materials. The church received 4 points in the innovation in design category.

5.8. Regional Priority

The building has regional priority due to its location, interaction with the sea, proximity to public transport, location between the two central districts of Fener and Balat, and its location in the historic district of Fatih in Istanbul. The church has been awarded 7 points in the regional priority category.

When analysed in terms of Energy Efficiency and Renewable Energy Use, Building and Historical Value, Indoor Environmental Quality, Material Sustainability and Conservation Techniques, Sustainable Areas, Water Efficiency and Management, Innovation in Design and Regional Priority, the church receives a total of 48 points on the model. Sveti Stefan Church has been evaluated through the model created in line with the principles of sustainable architecture and green building certification systems. In line with the results obtained, it was concluded that the level should be increased. In this direction, suggestions are presented in the following sections.

6. Discussion

6.1. Strengths and Limitations in Green Adaptation

The need for sustainable energy sources in terms of Turkey's energy production and consumption, as well as the country's potential, are identified within the framework of its strengths and limitations.

Strengths:

- The fact that sustainable energy sources mostly do not require high technology facilitates resource utilisation.
- Turkey has significant potential for various sustainable energy sources due to its geopolitical location.
- Using sustainable energy sources for electricity generation will be effective in maintaining ecological balance by reducing fossil fuel consumption.
- Energy imports will be significantly reduced, leading to economic improvement.

Limitations:

- The current economic situation results in limited investment in energy sources.
- Global climate issues.
- The lack of awareness among the population hinders the use of sustainable energy sources (Doğan, 2015; Gürcün & Petek, 2021; Yılmaz, 2018).

6.2. Potential Improvements and Best Practices

- Within the scope of the identified strengths and limitations, training programs on sustainability and green energy-green building certifications should be organized to raise user awareness.
- Governments should implement incentive programs to promote green building certification systems and increase their adoption.
- Factories producing materials should be established with measures ensuring easy access to materials without negatively impacting human health.

- Governments should ensure energy production through ecological means and support the use of green energy in buildings as a result.

Sustainable architecture is an issue that needs to be popularised because we are located in a geography with high historical value and geopolitical location that is suitable for sustainable designs. First of all, when it is started to be applied in the historical environment, it has the potential to increase the value of the historical environment and provide support for restoration works.

7. Conclusion and Recommendations

Owing to the site's coastal context, seawater and prevailing winds are identified as critical environmental parameters in this analysis. The building currently receives no credit under the Energy and Atmosphere category; however, it is proposed that a wave energy conversion system be integrated by installing capture chambers along the shoreline (Fig. 6). This renewable energy system could be located in the basement of the church and designed as a publicly accessible exhibit, thereby demonstrating the integration of contemporary energy technologies within a historical structure. This solution not only enables on-site energy generation but also contributes to optimizing the building's energy performance and reducing overall consumption. As a result, the building fulfills all criteria within the Energy and Atmosphere category, adding 17 points to its green building assessment.

In addressing the third criterion under the Materials and Resources category—related to the maintenance of both structural and non-structural components—it is essential to implement a scheduled maintenance program. This program should outline routine inspections and the systematic upkeep of building elements at defined intervals. Such proactive management ensures the ongoing preservation of the structure and satisfies criterion 3, thereby contributing an additional 4 points to the overall sustainability evaluation.

In the case of the church, rainwater is collected from the roof and directed through vertical downpipes integrated within the structural columns, channeling the water to the ground and into perimeter drainage systems surrounding the building. To enhance water efficiency, it is proposed that this rainwater be stored in a subterranean reservoir to be constructed within the church garden, specifically for irrigation purposes. This system enables the reuse of rainwater for landscape maintenance, effectively reducing the building's overall water demand. By fulfilling Criteria 1, 2, and 4 under the Water Efficiency category, the building earns an additional 3 points.

As a result of the proposed interventions, the building receives a total of 24 additional points under the green building assessment framework for historical contexts. This improvement elevates the church's score from 48 to 72 points, advancing its certification from one star to three stars.

The study and the assessment model developed herein underscore the potential for integrating sustainability principles into the conservation and evaluation of heritage buildings through the application of green building certification systems. This approach highlights how historical structures can actively contribute to sustainable architectural practices when assessed with context-sensitive criteria.

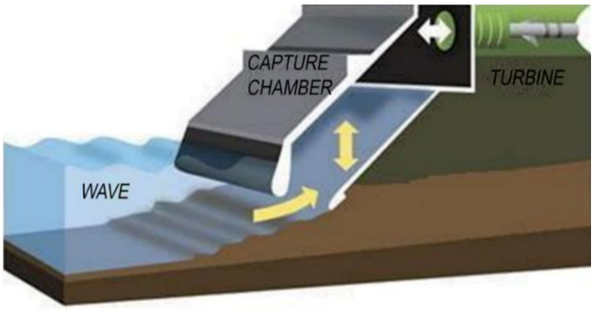

Fig. 6. Electricity generation through wave energy
(https://evcedyetkilendirme.enerji.gov.tr/teknoloji/dalga_en_urt_sistemleri.aspx)

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Deterioration in buildings: A study on failure analysis and solutions

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Abstract. Buildings are exposed to various effects over time from the first day they are built. As a result of the impacts, deterioration may occur at different points such as building elements and materials. This situation negatively affects the functionality, safety, health, and aesthetic value of buildings, while increasing repair and maintenance costs. Understanding the causes of building deterioration and developing solutions to these problems is important for the design, construction, and use of the building. The study prepared in this direction aims to understand the main causes of deterioration in buildings through the example of a residential building and to offer solutions for the deterioration detected. The study aims to develop measures for long-lasting and durable structures by revealing the interaction of environmental and human-induced factors related to the deterioration of buildings. Environmental factors focus on physical, chemical, biological, climatic, and mechanical factors, while human-induced factors are discussed under the subheadings of design errors, material selection errors, workmanship/ application errors, inadequate supervision, and usage errors. The effects of these factors on building elements were identified and classified through a literature review. In the context of the information obtained, a comprehensive observational study was conducted on a residential building. In the study, the deterioration of the building was determined, the causes of the deterioration were analyzed in the context of environmental and human-induced factors, and solution suggestions were presented. As a result, it was observed that the main causes of deterioration were physical factors, workmanship/application errors, and inadequate supervision. It is thought that the study will be an example of raising awareness on the prevention of building deterioration and designing durable and long-lasting structures.

Keywords: Structure; Deterioration; Error; Causes of deterioration; Structure analysis

1. Introduction

Individuals expect the places they live in to be safe, healthy and comfortable. However, deterioration can occur in different areas in structures during the design, construction and usage periods. Deterioration can be caused by physical, chemical and biological environmental factors such as heat, water, humidity and climate, and in addition to these, human factors such as usage error, workmanship/application errors, inadequate supervision etc. Some deteriorations cause visual discomfort while others can cause danger to the structure. Therefore, it is important to be informed about the causes of deterioration, to be able to detect the source of the errors and to be able to suggest solutions for the repair of deterioration.

2. Materials and methods

Within the scope of the study, the factors causing deterioration were examined under two main headings as environmental and human-induced factors. The causes of deterioration and possible solution suggestions were shared. In line with the data obtained through the literature review, a residential structure was selected in order to analyze the errors it contains. When selecting the structure, criteria such as access to sufficient information about the structure, the presence of different functions in the structure, the variety of materials in the interior and exterior spaces, and access to all open-to-use areas in the structure were taken into consideration. The structure constituting the field research was introduced by providing information about the way it was settled on the land, its identity, its purpose of use, the types of apartments it contains, and its other functions. Although there are many studies in literature examining different structures and sharing sample errors; it is thought that the detection of deteriorations that occurred in a structure completed in 2019 with current construction techniques within six years will contribute to the addition of current data and examples to the research field. 10 different deteriorations in the residential structure were determined to be examined in the study. The causes of the selected deteriorations were determined

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through observation, and solution suggestions for detecting errors and correcting the deterioration were shared. In this way, it is aimed to bring to literature sample methods that can be used in structures with similar deteriorations and errors.

3. Factors causing deterioration in structures

When structures are designed, they are expected to respond to the needs and desires of users. However, deterioration may occur at various times and in different places during the life of the structure. There are many different reasons for these deteriorations. However, if it is generalized, it can be said that faulty decisions and practices are the basis of deterioration. In this study, the factors that cause deterioration in the structure were discussed. Although the factors in question are related to each other, they were examined under two main headings as environmental and human-induced factors. While physical, chemical, biological, climatic and mechanical factors were examined under the main heading of environmental factors; design errors, material selection errors, workmanship/application errors, inadequate supervision and usage errors were discussed under human-induced factors (Fig . 1) (Coşgun, İpekçi, & Yılmaz, 2002). Although the factors were examined under separate headings, it is known that the causes of deterioration may affect each other and that the errors made may cause other errors.

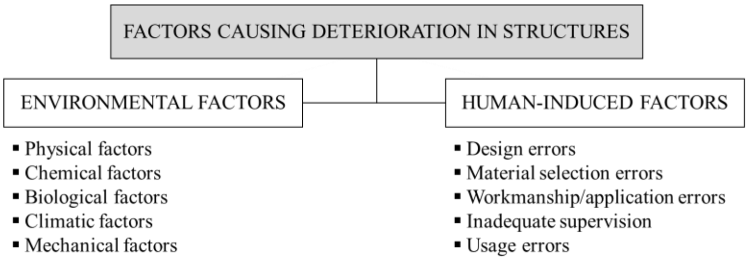


Fig. 1. Factors causing deterioration in structures

3.1. Environmental factors

During the construction and usage processes, structures that are open to external effects in terms of material, component and element dimensions are exposed to different environmental factors. Environmental factors are generally the result of atmospheric effects such as wind, sun, temperature, precipitation and humidity. Physical factors such as heat, water, humidity and climate; chemical factors such as sun rays, corrosion etc.; biological factors that occur due to the effect of bacteria/fungi/insects/worms; mechanical factors that occur depending on the properties of the material can be counted in the environmental factors group. In the structural elements exposed to these factors, deteriorations such as cracking, shedding, efflorescence, moss formation, corrosion and color change can be observed over time (Öztürk, 2017). If precautions are not taken against these factors and deterioration is not detected quickly when it occurs, it can cause major deteriorations inside and outside the structure.

3.1.1. Physical factors

The physical properties of the material are expressed with properties that can be measured by experiments such as size, volume, mass, conductivity, and expansion coefficient (Toydemir, Gürdal, & Tanaçan, 2000). Therefore, it is possible to define physical factors as effects that can change the properties of the material that can be measured by experiments. Factors such as heat, water, humidity, and fire can be included in the group of physical factors.

- Heat effect: Due to the temperature difference between two materials, heat passes from a hot object to a cold object. When the materials used in the structures are not selected according to this situation, problems occur in the structures. Thermal problems are among the most important issues that should be given importance in terms of the comfort of the individuals living in the structure, the physics of the structure and energy saving (Eriç, 2002). The heat changes experienced can cause shrinkage and expansion in the materials. Since the volume of the material increases when expanding and decreases when contracting, it can cause deterioration such as cracking, breaking and separation in the material unless precautions are taken (Fig. 2) (Croci, 1998; Esener, 2018). In order to prevent this situation, it is necessary to know the properties of the materials, choose the right material and solve the necessary details.

Fig. 2. Coatings falling off the facade of the building due to heat change (Güzelçoban Mayuk, 2007)

- Water and humidity effect: When the laws of physics are examined for the humidity and movement occurring in the building material, it is seen that it is caused by the pressure difference. Water vapor moves according to the partial pressure and passes from the area where the pressure is high to the area where it is low. During this transition, the vapor turns into water and sweats on the material (Eriç, 2002). Water and humidity can cause the heat retention properties of building materials to decrease, the material to disintegrate and swell, the formation of efflorescence, the occurrence of deteriorations such as corrosion and decay in the building elements, and the formation of mold and fungus (Fig. 3) (Yıldız & Dal, 2016). Therefore, taking precautions against water and humidity such as covering the building with a roof with wide eaves, choosing water-resistant paints and coatings on the building surface, using sills with drips in the joinery, and using drainage in the building will reduce the occurrence of problems in the building (Ekinci, İşçi, & Alyavuz, 2007).

Fig. 3. Swelling and flaking seen in the ceiling paint as a result of the effect of water and humidity in the building (Özdoğan, 2023)

- Fire effect: Fire can occur due to human error or environmental factors. As a result of fire, some or all of the structures burn. In partial fires, the elements of the structure are damaged, and the damaged parts need to be repaired or renewed. Selecting the materials used in the structure that are resistant to high temperatures can be a precaution against fire and can minimize damage.

3.1.2. Chemical factors

Chemical factors cause changes in the chemical properties of the materials used in the structures. As a result of sun rays and atmospheric effects, deterioration and aging occur on the surface or internal structure of the material. Sunlight can cause conditions such as color fading and hardening. In order to be protected from the effects of sun rays; choosing the color according to the place, designing wide eaves, designing sunshade elements, positioning the space and joinery layouts according to the sunlight needs can protect the structure from deterioration. Corrosion: is the situation where metal elements undergo dissolution or chemical change and wear as a result of various effects in the environment (Fig. 4). In order to be protected from corrosion, eliminating the factors that cause corrosion, coating the metal used with materials such as oxide, silicate or organic-based oil, bitumen and plastic can be offered as a solution (Eriç, 2002).

Fig. 4. Corroded column reinforcement (left), corroded railing (right) (Dal & Yılmaz, 2015; Peter, 2025)

3.1.3. Biological factors
Biological factors that cause deterioration in structures can be considered as plants, animals, insects, bacteria and fungi. When the roots of plants such as trees or ivy start to interfere with the elements of the structure, they cause deterioration in the building foundations and walls. In addition, the branches of the plants can hit the structures and cause physical damage to the structure. Animals can damage the structure by gnawing and dismantling the materials in the structure. Insects and fungi pose a major problem in wooden structures and structural elements. Fungi formation can be seen in wooden materials due to high humidity and insufficient ventilation. Bacteria, fungi and algae can cause decay and color change in the joints and internal and external surfaces of the structure (Fig. 5) (Öztürk, 2017; Zakar, 2013). To protect the structure from biological factors, regular checks should be provided, the building should be ventilated, and cleaning, maintenance and repair should be done in the structural elements/materials.

Fig. 5. Fungus and mold formation in the building (Interior, 2023)

3.1.4. Climatic factors
Climate, which affects a large area for many years and consists of elements such as sunlight, pressure, temperature, precipitation, and wind, is another factor that causes deterioration in structures (MGM, 2023). If the design and detail solution are not carried out according to the climate characteristics of the region where the structure is located, deterioration will occur in the structure as long as it is exposed to these elements. On the facade, which is the most exposed to external effects, wear, shedding, color changes, breaks, and cracks can occur due to rain and wind, and this can cause various deteriorations in the structure. In order to prevent deterioration, the material selection should be made correctly, and the structure should be maintained regularly.

3.1.5. Mechanical factors
The characteristics of the structure and the materials in the structure under mechanical loads such as pressure, tension, flexibility, elasticity and ductility are called mechanical factors (Eriç, 2002). Before the construction of the structures, the loads affecting the structure are made through static calculations. However, due to movements and loads that are not taken into account or that occur over time, deterioration may occur in the structures. Due to mechanical effects, wear, cracks, rounding of material edges and reduction in element cross-section may occur as a result of friction in the structure (Fig. 6) (Erdoğan, 1982; Öztürk, 2017). In order to eliminate mechanical effects, regular checks should be carried out in the structure and the deteriorated elements or materials should be repaired/replaced.

Fig. 6. Cracks caused using different materials in the building floor and wall (Özdoğan, 2023)

3.2. Human-induced factors
Many human deteriorations are observed in structures. Unconscious use of structures, lack of periodic maintenance and repair, wrong decisions made during the design phase, wrong material selection, workmanship/application errors and inadequate supervision can be shown as human-induced factors (Coşgun et al., 2002; Erdemir M., Erdoğan N. Ş., & Korkmaz S.Z., 2023).

3.2.1. Design errors
Deterioration in the structure can occur not only during the usage phase of the structure but also as a result of wrong decisions taken during the design phase. Design errors usually result from the lack of knowledge and care of the architect who designs the structure and the engineer who carries out the static solutions. Errors made during the design phase cause decisions to be made during the implementation phase and details to be resolved, and sometimes wrong choices cause deterioration in the structure. In addition, due to the lack of sufficient communication with the user during the project design phase of the space, dysfunctional and unusable spaces can emerge for the user.

3.2.2. Material selection errors
From the carrier system to the countertop material in the kitchen, even the smallest element/material in the structures must be selected after detailed research and its application must be done with the details solved in the appropriate place. At this point, it is important to know the chemical, physical and mechanical properties of the materials sufficiently. In the use of different materials together, the materials must be visual and mechanically compatible with each other. If qualified material selection is not made, deterioration occurs earlier and affects the quality of the structure. In addition, choosing materials in accordance with the location of the structure, climate characteristics and cultural data is one of the important points of a correct design.

3.2.3. Workmanship/application errors
The production sector of structures is an area that requires different disciplines to work together. Therefore, it is important to ensure sufficient coordination between the design and construction teams. As a result of unprovided coordination, communication gaps during the implementation phase cause problems in structures. In the architectural project, decisions may need to be made during the construction phase due to insufficient details that are not explained as necessary for the implementation to be carried out. This deficiency in the project attempts to be completed incorrectly or incompletely during the implementation. As a result, workmanship is carried out incompatible with the decisions in the project and faulty applications occur. Application errors resulting from unqualified workmanship cause damage that may cause discomfort during the life of the structure.

3.2.4. Inadequate supervision
Inspection of the structure should be carried out by the people responsible for the design, production and usage processes. Municipalities should examine the architectural project in detail when approving it, and during the construction of the structure, construction sites should be inspected by site managers and building inspection companies. During usage, regular inspections by users and authorized people will reduce the number of deteriorations that are at risk of occurring in the structure. To create long-lasting and healthy structures, inspections should be carried out at regular intervals on the structure's carrier system, materials and details. It is important for the life of the structure that the deteriorations detected during the inspections are conveyed to the necessary people and the problem is repaired/solved before it grows.

3.2.5. Usage errors

While individuals in the structure are using space, they can perform actions such as decreasing or increasing the load-bearing system elements of the structure, reducing the element dimensions and removing the filling elements. Since the calculations are made in accordance with the architectural project in the static projects where the load-bearing capacity of the structure is calculated, these interventions made at the time of use cause the static calculations to change. Changes in the loads of the structure can cause the load-bearing capacity of the structure to decrease. As a result of this situation, deterioration, collapse, collapse occur in the structure and cause loss of life. Not using the structures for a long time, leaving them unmaintained or abandoning them can lead to a decrease in the life of the structure. Building materials also have a certain life and it is necessary to perform maintenance on the building elements at different periods depending on their material. It is important for the user to show sufficient care in this matter to extend the life of the building elements and the structure. The maintenance and repairs to be made must also be carried out by qualified persons (Coşgun, İpekçi, Yılmaz, 2002).

4. Results and discussion

It can be said that two basic methods are mainly used in the detection of deterioration in the structure. The first of these methods is based on obtaining data through observation on the structural element where the deterioration occurs. When the cause of the deterioration is understood, error detection is made, and solution suggestions are presented, and the element/material is repaired or replaced. However, since the detections are made depending on the experience of the person, it can sometimes be ignored that there may be other errors that cause deterioration (Baytop, 2001). In the other method, errors are handled with the performance approach. In the performance approach, detection is also made based on observation, but unlike the other method, deterioration and errors are evaluated depending on performance requirements, criteria and measures. In this context, since the obtained data are obtained through analyses, the origin of errors that indirectly cause deterioration can be determined more clearly (Utkutuğ, 2006).

In this study, it was aimed at analyzing the deteriorations in a selected multi-storey housing site. While determining the deterioration, observation-based photography studies were carried out in the structure. In line with the collected data, the cause of the deterioration was tried to be determined. In this context, solution suggestions were presented based on the information obtained from the literature and experience in the repair or elimination phase of the deterioration.

4.1. Building information

The housing site determined to be examined was completed in 2019 and consists of eight blocks (four buildings in a detached order) and 155 flats placed in the northwest direction of the land. The flats in the blocks vary in normal and duplex forms as 4+ 1, 3 +1, 2+1 and 1+1. The structure consists of a basement, ground floor, three normal floors and an attic. The load-bearing system is reinforced concrete skeleton, and the floor type is designed as slab and hollow-tile slab. The wall filling material is brick, aerated concrete and plasterboard. The structure can be reached on foot from the main entrance and by vehicle from the three parking lot entrances. Due to the elevation difference in the land where the structure is located, the blocks sit on different elevations. In the landscape areas, there is a security cabin, open adult and children's pool, ornamental pool, children's park, sports area, cafeteria and green areas.

4.2. Deterioration detected in the field study and their analysis

In the study, 10 of the deteriorations observed in the structure for field research are presented in a table under the titles of deterioration detection, causes of deterioration, error detection and solution suggestions for deteriorations. While detecting errors that cause deterioration, the basic error that may cause deterioration is written in the first place. In addition, in the stage of presenting solution suggestions, suggestions are presented starting from the easiest and fastest solution for the problem. The detected deteriorations are shared in each line. The examination of 10 deteriorations including the mentioned stages is given in Table 1.

Table 1. Deterioration analysis

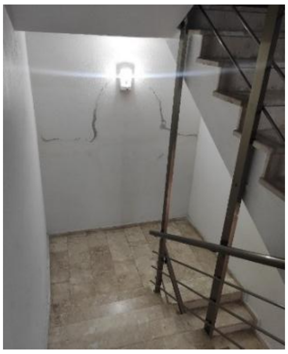
No	Deterioration Detection	Causes of Deterioration	Error Detection	Solution Suggestions
1	 Swelling, flaking and discoloration on the wall	Swelling, flaking and color change are effects of water and humidity in structures. Plaster and paint that swells by taking in water show shrinkage in volume when dry. This is why flaking occurs.	▪ Workmanship/ application errors ▪ Material selection errors	The waterproofing application in the wet area behind the damaged wall can be checked and re-done. In case the water flow path is an electrical channel to which the lighting is connected, the channel can be insulated.
2	 Crack in the wall	Incompatibility may occur between the reinforced concrete load-bearing elements of the structure, the infill wall located between the columns and beams, due to material differences. Settlements may occur between the infill wall elements over time. In the infill wall application, the connection of the wall to the load-bearing system may not be provided.	▪ Workmanship/ application errors	The part where the crack is located can be scraped. After applying filler/plaster to the scraped area, the surface is sanded and plastered by placing plaster wire on it. Then, a layer of paint can be applied.
3	 Deflection and water accumulation in the winter garden cover	Roofs must be designed and implemented in a way that allows rain/snow water to drain off the surface as quickly as possible, depending on climatic conditions. In the detected example, the intermediate joint lines were not applied parallel to the slope. This situation caused water accumulation on the surface and deflection of the surface of the affected material over time.	▪ Design errors ▪ Workmanship/ application errors ▪ Inadequate supervision	By opening channels between horizontal logs and providing the necessary waterproofing, water can be ensured to flow in the direction of the slope and pour into the gutter. The system can be disassembled and re-configured to be parallel to the roof slope.

Table 1 continued

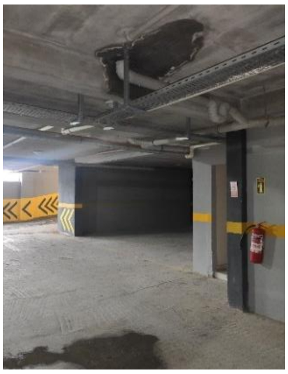
4	 Paint and plaster peeling off in the area where the expansion joint is located on the wall	The top of the expansion joint in the project was not covered with a flexible element but was covered directly with plaster and paint. Movement occurred in the joint due to the movements that occurred as the building settled on the ground over time. Since the plaster is a brittle material, it cracked and the flaking on the surface grew larger over time.	▪ Design errors ▪ Material selection errors ▪ Workmanship/ application errors	On the walls where the dilatation is located, the plaster can be scraped off and the dilatation can be covered with curved insulation material, but plaster should not be applied on it and should be left open. Otherwise, the plaster will crack again.
5	 Moss formation, discoloration and shedding on the wall	When walls are not adequately protected from water and moisture and are constantly exposed to them, moss formation occurs in places where water leaks. Especially in areas that do not see the sun (north facades), moss formation is easier. The surface here is in the northwest direction and there is a waterproofing problem in the area above the wall.	▪ Workmanship/ application errors ▪ Inadequate supervision ▪ Usage errors	Water insulation can be applied to the source of water leaking into the wall. After the mossy layer on the wall is scraped off and the moisture dries, the wall can be sprayed with ready-made pesticides produced for mossy growth.
6	 Water leakage from the part where the water drains are located on the parking lot ceiling	Water can leak from the smallest crack in the structure. Therefore, spaces exposed to water should be well insulated against water. Especially in the parts of the structure where water drains are located, if the relationship between the water pipes and the ground is not resolved well, water leaks can occur as in the example.	▪ Workmanship/ application errors ▪ Inadequate supervision	By removing the pipes and finding the source of the leaking water, the junction point with the floor can be insulated against water.

Table 1 continued

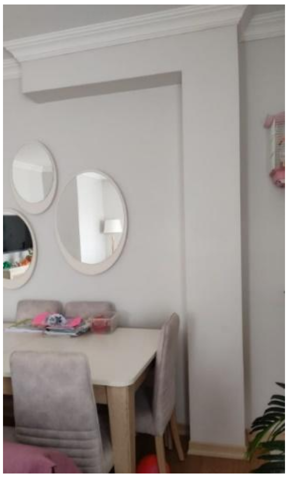
7	 The presence of a protrusion that makes the living room wall useless	If the correct solutions are not made for the water drains of wet areas, it is necessary to close the water drains from the ceiling and wall of the hall as in the example. In this case, when the wet area on the upper floor is used, the sound of water is heard in the volume. In addition, there is a problem in furnishing.	▪ Design errors ▪ Workmanship/ application errors	Furnishings can be made in a way that will include/eliminate the protrusion on the wall. A shelf system can be designed. For sound, insulation can be applied, although it will increase the protrusion area.
8	 Scratches/abrasions on elevator doors	The doors may not have been placed in the elevator door shaft on a level. As a result, the doors rub against the shaft during opening and closing and wear occurs on the door surface. Another reason is that the elevator shaft may not have been placed on a level.	▪ Workmanship/ application errors ▪ Inadequate supervision	The problem can be solved by checking the elevator shaft and the balance of the doors. If the problem is with the elevator volume, the volume may need to be re-balanced.
9	 Mold formation on the wet area wall. Opening the door to the outside and the step	Mold fungus, which appears in different colors such as black, navy blue, green and spread over the entire surface, forms in secluded, cold, airless and damp areas where sweating occurs and accumulates. Ventilation and wall details must be resolved in accordance with the wet area.	▪ Design errors ▪ Material selection errors ▪ Workmanship/ application errors ▪ Inadequate supervision	Plasterboard walls can be removed and replaced with water-repellent green plasterboards. A mechanical system can also be installed to ventilate the space.

Table 1 continued

10	 The residence waste water drains are located in the open and the pipes are connected to each other at right angles.	The wastewater drainpipes in the basement are open to external effects. There is a possibility of hitting the pipes while parking the car. In addition, the pipes should be connected at a certain slope to prevent blockage in the pipes. There is a possibility of blockage and the pipes bursting.	▪ Workmanship/ application errors ▪ Inadequate supervision	The sections of the pipes that meet at right angles can be sloped. Then the area can be closed with a protection wall/iron barrier.

5. Conclusions

Structures shaped according to the needs of the users must provide certain comfort conditions. However, deteriorations may occur due to different reasons in the design of the structure, during the implementation phase and during the usage period. In the study, 10 of the deteriorations determined in the housing site selected for field research are presented under the titles of deterioration detection, causes of deterioration, error detection and solution suggestions for deteriorations.

When the obtained data is examined, many problems such as swelling/shedding/cracks/fungus/mold/moss/color change on the walls, dirt on the walls, plaster/paint flaking, water leaks, breakage/separation/wear in the structural elements are encountered in the detection of deterioration. As the detection of deterioration differs, the factors causing deterioration also to change. However, it can be said that the deterioration in the structure is mainly caused by physical factors such as water and humidity problems. It is thought that the fact that the structure is in the northwest direction influences this situation. Wet surfaces need to be ventilated and dried. However, due to its location in the northwest direction, there is little sun exposure in the structure. Therefore, wet areas cannot dry and this can cause problems.

When the fault detections of the deteriorations examined in the structure were made, it was seen that there were mainly workmanship/application errors and inadequate control. This was followed by design errors, material selection errors and usage errors. Table 2, which summarizes the fault detections according to deterioration numbers, can be accessed below.

Table 2. Summary of error detections according to the deterioration number.

ERROR DETECTION	DETERIORATION DETECTION NUMBER									
	1	2	3	4	5	6	7	8	9	10
Design Errors			✓	✓			✓		✓	
Material Selection Errors	✓			✓					✓	
Workmanship/application errors	✓	✓	✓	✓	✓	✓		✓	✓	✓
Inadequate supervision					✓	✓		✓	✓	✓
Usage Errors					✓					

The reason why almost all errors are encountered with workmanship/application errors and inadequate supervision is that the companies contracted to carry out the application process of the building do not do their jobs well enough. Even if the design of the structure is done correctly, poor application during the construction phase can cause many deteriorations in the following processes. Since the errors made during the construction phase were not inspected on site and at the right times, deteriorations could not be prevented. Another most encountered error in the examined areas was the design error. Errors were encountered at the points of the structure that would meet the needs and comfort of the users or in the areas expected to fulfill the purpose of use. Among these errors, design, workmanship/application and inadequate supervision errors are the most difficult errors to repair/repair/correct/renew. Finding the source of the error and the solution can be long and difficult. Usage errors, which can be solved relatively faster, are the least common errors.

When it is desired to minimize the deterioration in structures, it is important for the individuals involved in the implementation and usage processes to do their jobs meticulously, starting from the project/design phase of the structure. During the material selection phase, it is necessary to have a good command of the chemical and mechanical properties of the material and to make good, detailed solutions. It is also important to perform periodic maintenance and repairs during the usage phase. Correctly determining the causes of deterioration and fault detection in structures prevents the deterioration from growing and allows the solution processes to accelerate. Therefore, when deterioration is encountered, it is necessary to start detection work quickly.

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Evaluation of 3D concrete printing production processes with multicriteria Decision-Making methods

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Abstract. Recently developed construction technologies have made it possible to carry out processes more efficiently, quickly and sustainably. In this context, 3D concrete printing technology, automation, and robot technologies have emerged. This study aims to verify the reliability of the results obtained through experimental methods in producing different geometric forms in the 3D concrete printing process using multi-criteria decision-making (MCDM) methods. The study's main purpose is to examine the effectiveness of MCDM methods in verifying experimental data and to prevent waste of time and resources in experimental processes. The data obtained in the experiments were analysed using the selected MCDM methods, and it was determined that the circular geometry plan provided the optimum performance in terms of buildability, cost, and mass producibility parameters. MCDM analyses similarly showed that the circular geometry plan was superior regarding these parameters. The results revealed that the selected MCDM methods were broadly consistent with the experimental findings, and it was also determined that the methods were sensitive to different criterion weights and assumptions. This study demonstrates that MCDM methods can effectively support experimental results and serve as a valuable complementary tool in decision-making processes. The findings highlight the effectiveness of using experimental and theoretical approaches in decision-making processes.

Keywords: 3D concrete printing technology; automation; robot technologies; MCDM

1. Introduction

As one of the key technologies of Industry 4.0, additive manufacturing enables the production of products designed in a digital environment using the 3d printing (3DP) method. This technology, first developed in 1983, has become widely adopted in various sectors today, including automotive, aviation, and construction. In the construction industry, 3d printing (3DP) is used as an alternative to traditional molding methods, enabling the production of non-linear, complex architectural designs. This technology offers advantages such as reducing costs, shortening project time and ensuring sustainability by increasing automation and digitalisation in construction processes (Gebel et al., 2024; Takva et al., 2024).

In additive manufacturing processes, the selection of alternative building forms should be considered within the framework of criteria such as manufacturability, cost and sustainability. Multi-criteria decision-making (MCDM) methods can be an effective tool in such decision-making processes, as they save time and resources compared to traditional experimental approaches.

Multi-criteria decision-making (MCDM) methods typically involve processes such as determining alternatives, weighting criteria, and ranking options (Brugha, 2004). Majumder (2015) emphasises in his study that the correct result may not always be achieved in decision-making processes (Majumder, 2015). This study evaluated the similarities and differences between the results obtained using MCDM methods and the findings of a real-life experiment. The study's primary objective is to determine whether the results of an experiment can be accurately predicted using MCDM methods without the need for resources such as time, materials, and labour typically required for experiments.

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2. Methodology

In this study, the authors' experiment for producing different forms using 3D concrete printing (3DCP) is tested using multi-criteria decision-making methods. Information is diverse, and designers' priorities differ in the field of design (Tan et al., 2021). In MCDM methods, the goal is to optimise the evaluation of experts and decision-making. At the first stage, the parameters to be evaluated will be explained. Then, the criterion weights will be calculated using the Fuzzy AHP method, demonstrating the relevant criteria's importance. At this stage, pairwise comparison matrices are created based on expert assessments. With this evaluation, weights are obtained. After these weights are received, the alternatives will be evaluated with the TOPSIS method, and the resulting ranking will be compared with the actual result. The flow chart for the explained algorithm is shown in Fig. 1.

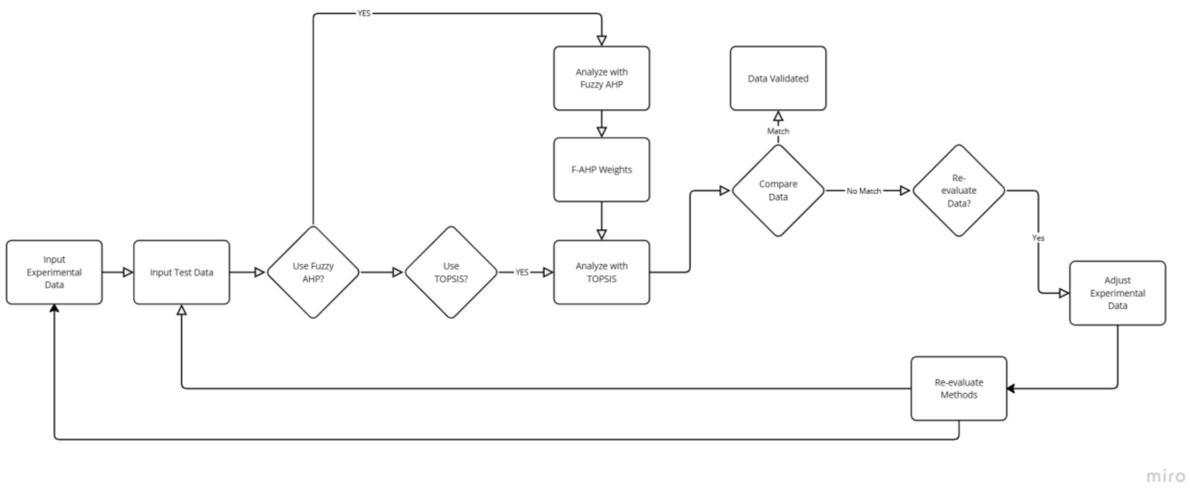


Fig. 1. Flowchart of the study

2.1. Fuzzy AHP

In the analytical hierarchy process, pairwise comparisons contain uncertainty because they are based on expert opinions; therefore, the Fuzzy AHP method is used in the literature to mitigate these situations. In this method, instead of evaluating with numbers (1-3-5-7-9) in AHP, experts are ensured to evaluate using linguistic expressions (Liu et al., 2020). The scale used in creating the fuzzy pairwise comparison matrices for the study is presented in Table 2.

Table 2. Linguistic variables (Huang et al., 2012)

Code	Linguistic Variables	L	M	U
1	Equally important	1	1	1
2	Intermediate value between 1 and 3	1	2	3
3	Slightly important	2	3	4
4	Intermediate value between 3 and 5	3	4	5
5	Important	4	5	6
6	Intermediate value between 5 and 7	5	6	7
7	Strongly important	6	7	8
8	Intermediate value between 7 and 9	7	8	9
9	Extremely Important	9	9	9

The fuzzy AHP method was applied through a series of steps that began with comparing pairs of criteria among experts. First, fuzzy decision matrices were created due to these comparisons and the fuzzy scale in Table 1 was used. Then, the fuzzy weights were normalised by calculating the consistency of the weights. Global fuzzy preference rankings were created for the alternatives, and the results were interpreted to guide the decision process. As a result, the rankings obtained by this method support the decision-making process. The findings obtained through the application of the method revealed the priority criteria for the 3D concrete printing process.

2.2. TOPSIS

The TOPSIS method is a straightforward and comprehensible technique that seeks to identify the alternative that is closest to the ideal solution and the farthest from the negative ideal solution in decision-making processes (Yoon & Hwang, 1995). The steps of the method are as follows: The creation of the decision matrix begins with normalising this matrix and obtaining the weighted decision matrix by taking into account the weights of the criteria. Then, the distances of each alternative from the ideal and negative ideal solutions are calculated. In the last stage, the relative proximity scores of the alternatives are determined, and the alternative with the highest score is selected as the best option. Due to its ease of application and the fact that its results are not subject to interpretation, the TOPSIS method is widely used in various fields (Fayaz et al., 2023; İlerisoy & Gökgöz, 2023, 2024; Lolli et al., 2022; Wang & Wang, 2014; Xiong et al., 2021).

3. Proposed Framework with Example

In this study, which compares the real-life application of 3DCP technology with the MCDM methods, the effectiveness of the MCDM methods in validating experimental data is measured. The TÜBİTAK project, with code 122M876, is used as experimental data. This experiment aims to identify errors and deficiencies by examining design parameters through models and to reveal the effects of these parameters by comparing them with one another. Building evaluation parameters based on research findings in the literature include comparative analyses of systematically modified design decisions in buildings with the same architectural plan and footprint. These analyses focused on specific structure evaluation criteria for geometric forms derived from 3DP. These are printing time, material usage, mass production, buildability, defect analysis, size consistency and cost criteria. As geometric forms, the square, chamfered square, rectangle, chamfered rectangle, circle, chamfered circle, hexagon, chamfered hexagon, octagon, chamfered octagon, and ellipse were evaluated, and these forms were considered alternatives in this study. The decision tree for this evaluation is given in Fig. 2.

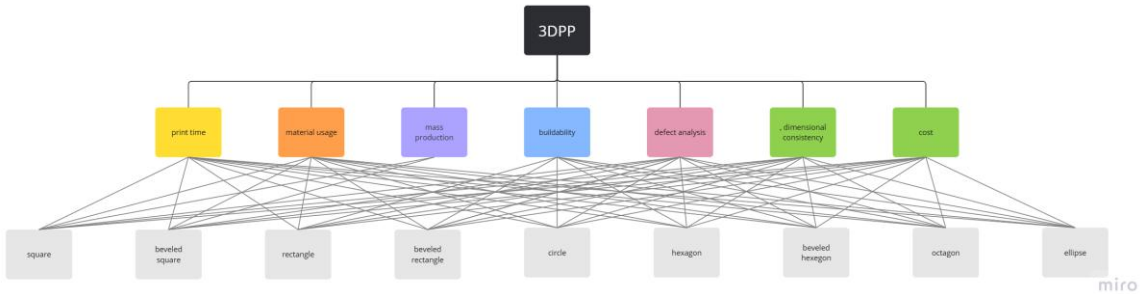


Fig. 2. Decision tree

This hierarchical evaluation was conducted by an expert team comprising five architects and five civil engineers who have specialised studies on the subject. The comparison matrix is presented in Table 1. Accordingly, the criterion weights in the criterion evaluations are given in Table 2.

Table 2. Criteria Weights

Criteria	Printing time	Material usage	Mass production	Buildability	Defect analysis	Dimension consistency	Cost
Weights	0.054	0.081	0.399	0.220	0.032	0.032	0.182

According to these evaluations, it was concluded that mass production was the most important parameter. The mass production parameter is crucial in determining the product's potential for mass production. The sum and analysis of the data obtained from other evaluation criteria help determine the systems suitable for mass production. In this process, the most appropriate mass production method and process should be determined by considering factors such as printing time, material usage, buildability, analysis of potential defects, measurement consistency, and cost. In this context, important factors such as production efficiency, quality standards, and cost-effectiveness are optimised, and successful results are obtained in mass production. The following criteria follow the mass production criterion, respectively: Buildability (0.220), Cost (0.182), Material Use (0.081), Printing Time (0.054), Defect Analysis (0.032), and Dimensional Consistency (0.032).

Buildability is the most critical parameter in evaluating printable mixtures. The extruded filament must maintain its shape without deformation, settle in harmony with the lower layers, gain sufficient stiffness and rapid strength, and form a strong bond between the layers (Ahmed, 2023).

The cost parameter, which ranks third after the buildability criterion, is a critical factor in determining the most economical geometry and is of great importance for applicability and mass production processes. The use of materials is a decisive factor in the printing phase, as the impact of different types and proportions of components on the final 3D printing (3DP) product is significant. Printing time stands out as a dynamic variable that is affected by other parameters and also affects them. Within the scope of defect analysis, the ability of different geometric forms to reach different layer heights is evaluated. On the other hand, dimensional consistency is an important criterion that examines the difference between input (design) and output (prototype printing) products.

In the evaluation using the TOPSIS method, the expert team evaluated the alternatives on a scale of 1 to 5. A ranking was created according to the criterion weights derived from the fuzzy AHP. Expert evaluation data are presented in Table 3, and normalised data are presented in Table 4.

Table 3. TOPSIS Expert Evaluation

Weights	0.054	0.081	0.399	0.220	0.032	0.032	0.182
Geometric Forms	Printing time	Material usage	Mass production	Buildability	Defect analysis	Dimension consistency	Cost
Square	3	3	3	3	2	3	3
Beveled Square	4	4	4	4	2	3	4
Rectangle	3	3	3	3	2	3	3
beveled rectangle	4	4	4	4	2	3	4
Circle	5	5	5	5	2	3	5
Hexagon	3	3	3	3	2	3	3
beveled hexagon	4	4	4	4	2	3	4
Octagon	3	3	3	3	2	3	3
Beveled Octagon	4	4	4	4	2	3	4
ellipse	5	5	5	4	2	3	5

Table 4. TOPSIS Normalization Data and Sequencing

	S+	S-	C	Rank
Square	0,082185378	0	0,00	7
Beveled Square	0,041092689	0,041092689	0,50	3
Rectangle	0,082185378	0	0,00	7
beveled rectangle	0,041092689	0,041092689	0,50	3
Circle	0	0,082185378	1,00	1
Hexagon	0,082185378	0	0,00	7
beveled hexagon	0,041092689	0,041092689	0,50	3
Octagon	0,082185378	0	0,00	7
Beveled Octagon	0,041092689	0,041092689	0,50	3
ellipse	0,018527342	0,075661411	0,80	2

As a result of these evaluations, considering all the criterion evaluations, it was seen that the best alternative was the circle form. This is followed by ellipse, chamfered octagon, chamfered hexagon, chamfered rectangle, chamfered square, square, rectangle, hexagon and octagon.

When the data obtained from the experiment are analysed, when we look at the printing time and material usage, collapse heights, maximum number of layers during printing and perimeter lengths between square, rectangle, circle and ellipse geometric forms; circle in terms of printing time, circle in terms of material usage, circle in terms of collapse height and circle in terms of number of layers showed the best performance. The results are shown in Fig. 3-4. This shows the accuracy of the study model.

square

rectangle

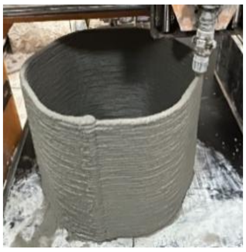
hexagon

octagon

beveled square

beveled rectangle

beveled hexagon



beveled octagon

Fig. 3. Collapsed views of square, rectangular, hexagonal and octagonal shapes with right angles and beveled designs and visuals of indestructible geometries

Collapse view of square form

Collapse view of rectangular form

The view where the circular form has not collapsed and has reached the maximum number of layers

Collapse view of ellipse form

Fig. 4. Collapsed appearances of forms

4. Results and Discussion

This section presents the results obtained with the multi-criteria decision-making methods used in the study and compares them with the experimental results.

Upon examining the findings obtained from this study, it was determined that the mass production parameter was the most important criterion (Fig. 5). This parameter is a comprehensive factor that optimises elements such as production efficiency, quality standards, and cost-effectiveness, and determines the impact of many other criteria. In this context, academicians who expressed their opinions in line with the experiments carried out in the laboratory environment also emphasised that the mass production parameter is the most important criterion. Thus, the criterion evaluation obtained in the multi-criteria decision-making analysis overlapped with the important criteria determined in the experimental environment.

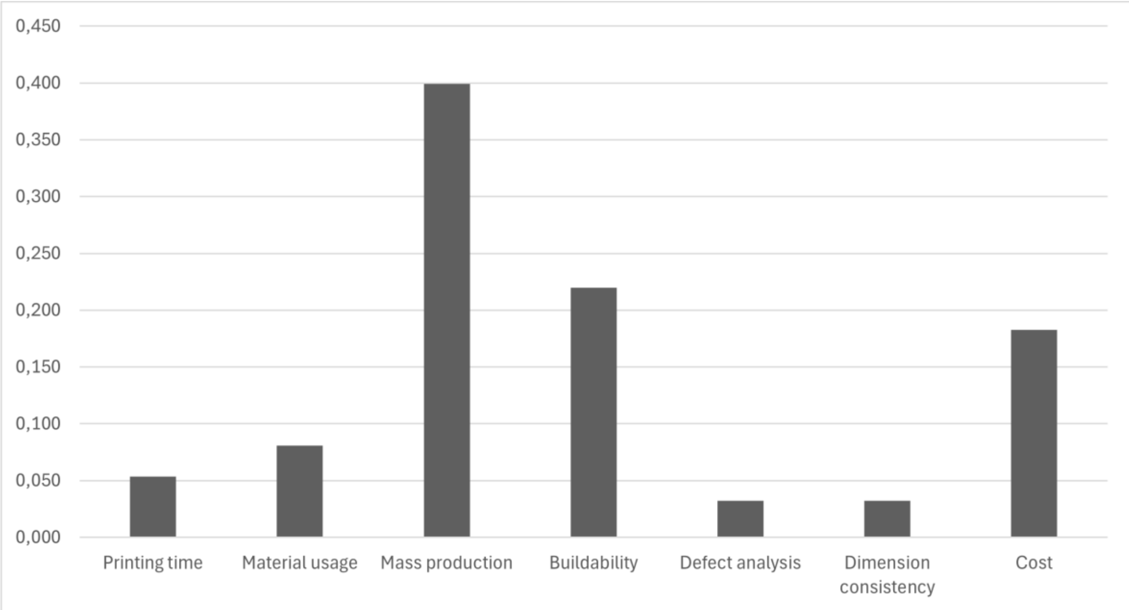


Fig. 5. AHP Results

The buildability parameter is crucial for successful printing. The filament needs to retain its shape, merge well with the layers and harden quickly. Otherwise, the print quality may decrease. In this parameter, a result was obtained that matched the experimental environment.

Printing processes on forms include printing time, material usage, mass production, buildability, defect analysis, and dimension consistency. The circle form got the best results in evaluating the cost criteria, and the presence of the circle form in the experiment shows that the model in this study works (Fig. 6).

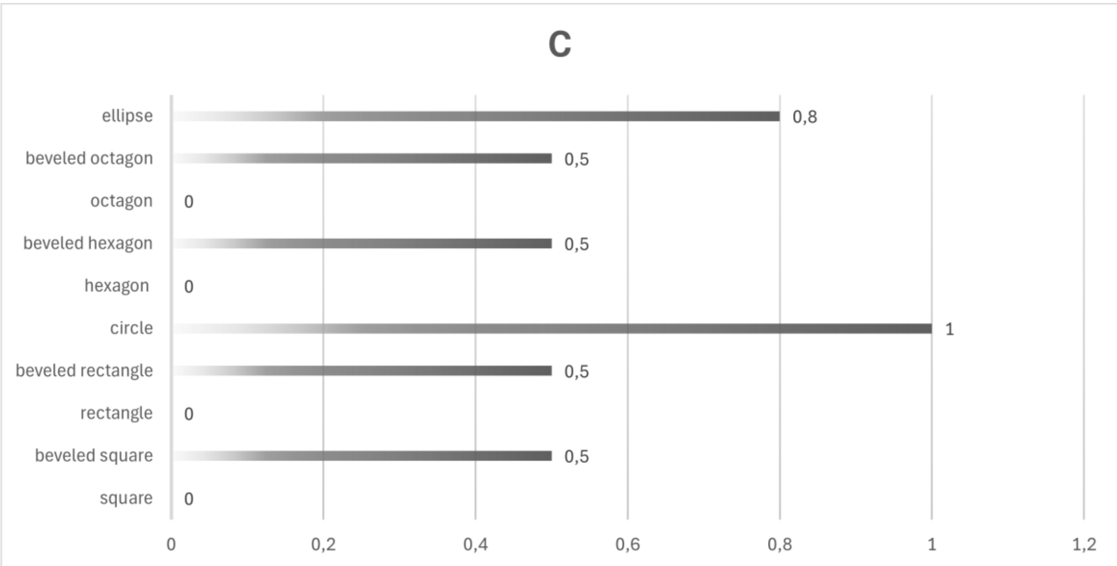


Fig. 6. TOPSIS Results

As a result of these evaluations, it was determined that the most suitable alternative was the apartment form, taking into account all relevant criteria. The circle is followed by an ellipse, a beveled octagon, a beveled hexagon, a beveled rectangle, a beveled square, a square, a rectangle, a hexagon and an octagon, respectively. The most effective criteria for the emergence of these results were mass production, buildability and cost. In the evaluations conducted in the experimental environment, it was found that the circle form exhibited the best performance, particularly when all criteria, including these parameters, were considered. This situation demonstrates that the results obtained using the Multi-Criteria Decision Making (MCDM) method are consistent with experimental studies.

4. Conclusion

This study showed that multi-criteria decision-making methods can evaluate alternative solutions without requiring the use of resources in experimental processes. The results obtained largely align with the experimental findings, indicating that MCDM methods can be a valuable tool in decision support processes. In future studies, the effectiveness of these methods in different decision settings and with more complex criteria may be examined in more detail.

The findings of this study reveal that the most important parameter in the three-dimensional concrete printing process is mass production. Mass production is a critical factor in determining the suitability of the prints for production processes and the efficient operability of the system. When the alternatives were evaluated by experts within the framework of all parameters, it was determined that the best-performing form was the circle. The circular form has demonstrated high performance in all parameters due to its soft lines along its circumference, which enable it to exhibit superior performance compared to other forms.

In this context, the study's findings can be considered an important step in developing alternative approaches to experimental methods in decision-making processes. Experimental studies entail the consumption of resources, such as time, materials, and labour, which can lead to both material and moral losses. Using Multi-Criteria Decision-Making (MCDM) methods, criteria can be weighted, and alternatives can be analysed systematically through expert evaluation questionnaires. Thus, comprehensive and efficient assessments can be carried out without wasting resources.

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A brief overview of historical water supply structures in ancient Tabriz

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Abstract. Tabriz is a historical and ancient city located in the northwest of Iran with a dry and cold climate. This city has been one of the largest commercial, political, educational, and cultural centers of the South Caucasus and Eastern Anatolia along the Silk Road. From ancient times, the inhabitants of Tabriz and other cities in the Iranian plateau created large water reservoirs and underground channels known as qanats to cope with water scarcity. The water stored in qanats was transferred through clay pipes underground to the reservoirs located in neighborhoods and houses, where it was stored and used in structures called sardab. Until years ago, before the water supply of Tabriz was provided through piping, the aforementioned historical structures played a significant role in supplying water to this city and its prosperity. In this research, using a descriptive-analytical approach, maps and information related to historical structures were first collected through existing documents and books, and then the method of water supply and distribution in the city through these existing structures was examined. The results show that over time, due to lack of use, change of function, destruction, and burial of the paths of most qanats, water reservoirs, and sardabs, they have disappeared in the city of Tabriz. Field studies indicate that only a very limited number of these historical water supply structures still remain and are sometimes in use. In this research, the structure, architecture, and method of operation of a number of these remaining structures have been examined and analyzed.

Keywords: Historical structures; Qanat; Water reservoir; Sardab; Tabriz.

1. Introduction

Certainly, the early inhabitants of Tabriz, like other human communities, were engaged in efforts to access water. At times, they utilized the most basic resources, and gradually, with the expansion of the city and urbanization and the increasing need for water, they implemented suitable solutions according to the conditions of time and place to ensure access to water for all. Over time, the river water that has flowed through this city since ancient times, along with the water from the springs along the rivers or those found in various corners of the plain, was insufficient for the community of that day. On the other hand, it was difficult for those who had lived together and become accustomed to one another to detach from their community. Thus, the increase in population and the expansion of society necessitated planning for water supply, which manifested in various ways throughout history. It is evident that the historical ups and downs, wars, and the destruction resulting from them have obscured certain periods of history, leaving no trace of the methods of water supply and distribution during those times. It can be said that the first period of water supply in Tabriz dates back to the Ilkhanate period of the Mongols. Furthermore, every city throughout its history has had its own methods for water distribution, yet unfortunately, there is ambiguity and darkness surrounding the issues related to water. Tabriz is also among those cities that have made necessary efforts throughout history to supply and distribute water. For example, during the Qajar era and the reign of Fath Ali Shah Qajar, due to the familial ties with Azerbaijan, more attention was given to the city of Tabriz, and water supply issues were resolved with the drafting of a text known as the "Fooladnameh." The Fooladnameh mentions that during the reign of Fath Ali Shah Qajar, under the efforts and insight of Fath Ali Khan Beiglar Beigi, a meeting was held in the capital city of Tabriz with the village heads and elders of the city and locality, as well as the wise deliberation of the Sadaat, to adopt a method for regulating water distribution. This was necessary because due to the disturbances and damages that had occurred, anyone from the residents could access water without rules or laws, and those who were situated at the source were successful, while many others suffered from thirst and lack of water. It was decided that the water from the Mehran River would be distributed in an orderly manner among

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them. In the year 1950, the first water reservoir in Tabriz was put into operation. Prior to that, in addition to the water from the Mehran River, which supplied various areas of the city according to a plan, a significant number of qanats around Tabriz played an important role in providing drinking and agricultural water for the city. The digging of qanats became common to meet the water needs, and both individuals and legal entities engaged in the construction of qanats, a practice that continued until the late reign of the Qajar dynasty, and they were utilized. During the Qajar family era, when Tabriz was the crown prince's residence and the capital, the water supply and distribution methods in this city were at their peak of fame, and diggers were engaged in creating qanats in various parts of the city and its surroundings. During this period, about 70 qanats and springs with good water flow were active for supplying Tabriz (Hashemi, 2010).

The digging of the qanat was one side of the story, and the method of transferring water to the city of Tabriz was the other side. Since the city of Tabriz is situated in a plain surrounded by mountains, qanats were dug at the foothills, with the mother well on the slope of the mountain and the outlet of the qanat located near or sometimes in the center of neighborhoods. In neighborhoods where the outlet of the qanat was within the area, water taps were installed, and people would collect their needed water using buckets or other tools. However, in places where the outlet was far away, water bearers would transport water from the outlet to the people using carts, or the qanat water would be transferred through clay pipes from the outlet to the center of the neighborhood and sometimes to the yards of houses. After transferring the water, it was stored in cisterns for use when needed. The cisterns had openings to control the water level, but access to the inside of the cistern was practically impossible. Alongside the cisterns, there was an underground space known as the "sardabeh," which was used for retrieving the stored water and had many steps leading outside. Another structure known as the "icehouse" complemented the cisterns, using the low temperatures on the brink of freezing during winter nights in the desert to create ice. Another space that was fed by the qanat water was the "hozkhanah," which existed in most old houses. It was a summer room with a small pond in the middle, where the cool water helped to humidify and lower the air temperature on hot summer days. These complex yet practical structures and the way water is transferred from the mountains to the required locations through these structures have their own specific mechanisms. This article aims to showcase how these structures operate and how they supply water in the dry and semi-dry region of the city of Tabriz. Given that today Iran, including the city of Tabriz, is facing a serious water scarcity issue, familiarity with the structure of these structures and, if necessary, their revival may be a fundamental step in addressing this problem. However, the importance of paying more attention to these structures becomes evident when most of them are at risk of destruction due to the negligence of the relevant authorities.

2. Materials and methods

Tabriz is located in the eastern corner of a flat sedimentary plain with an area of approximately (55*30) square kilometers. This plain has a gentle slope towards the northeastern shore of Lake Urmia and is irrigated by several rivers, the most important of which is the Ajichay (Tolkhorud), which originates from the southwestern slopes of Mount Solan (Sabalan) and, after passing near Garajeh-Dagh, which is the northern boundary of Tabriz, enters the plain and flows northwest of the city. The Mehran River (current Midanchay), which flows through the center of the city, joins the Tolkhorud from the left. The elevation around various parts of Tabriz can be considered between 1350 and 1500 meters according to a Russian geographical map, and in the northeastern area of the city, Mount Ainli-Zinli (the shrine of Awn ibn Ali and Zayd ibn Ali) is visible, with an elevation of 1800 meters, acting as a ridge that connects the Qara-Dagh mountain range located to the north and northeast with the slopes of Mount Sahand, whose highest peaks are about 3547 meters (this mountain is located fifty kilometers south of the city). Since Qara-Dagh is a mountainous, unproductive, and sparsely populated region, and the large Mount Sahand occupies all the distance between Tabriz and Maragheh, Tabriz is the only suitable route for transportation between the east (route: Astara - Ardabil - Tabriz and Tehran - Qazvin - Miyaneh - Tabriz) and the west (route: Trabzon - Erzurum - Khoy - Tabriz). Finally, since the slopes of Mount Sahand create a very narrow passage along the eastern shore of Lake Urmia, the transportation route between the north (Transcaucasia, Qara-Dagh) and the south (Maragheh, Kurdistan) must pass through Tabriz. The weather in Tabriz is harsh in winter with abundant snowfall, and in summer, due to the proximity of Mount Sahand and the abundance of surrounding gardens, the weather becomes mild and temperate.

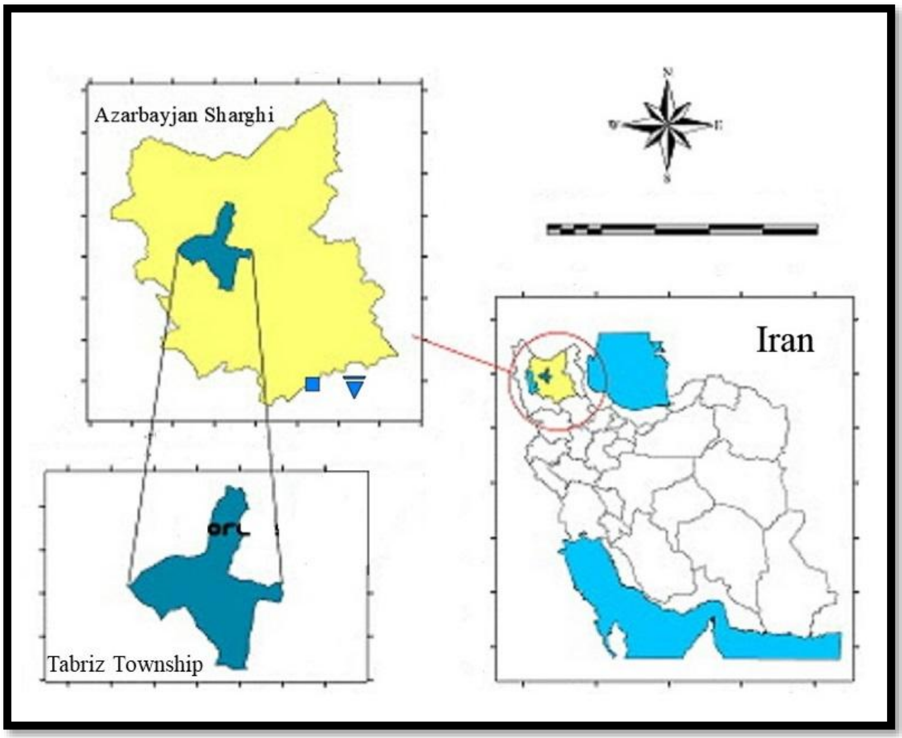

Fig. 1. Location of Tabriz city

In this research, with a descriptive-analytical approach, maps and information related to historical structures were first collected through existing documents and books, and then the way water supply and distribution in the city through existing structures was examined.

3. Results and discussion

3.1. Qanat

Iranians were pioneers in the construction of qanats, and after the Arabs took control of Iran, they brought Iranian qanat builders and specialists to North Africa to establish qanats. Ghirshman stated in his book "Iran" that the Iranian plateau has been irrigated manually since prehistoric times, and during the Achaemenid period, there were extensive underground networks known as qanats or kariz. The qanat was invented in Iran and gradually spread to other parts of the world, including the establishment of qanats in the Near East and the Middle East (in areas of present-day Eastern Turkey and Eastern Azerbaijan), in Africa, in South America near the Pacific Ocean, in Mexico, and in Europe in the region of Zelle in Germany, all of which originated from ancient Iran (Hashemi, 2010). (Fig. 2)

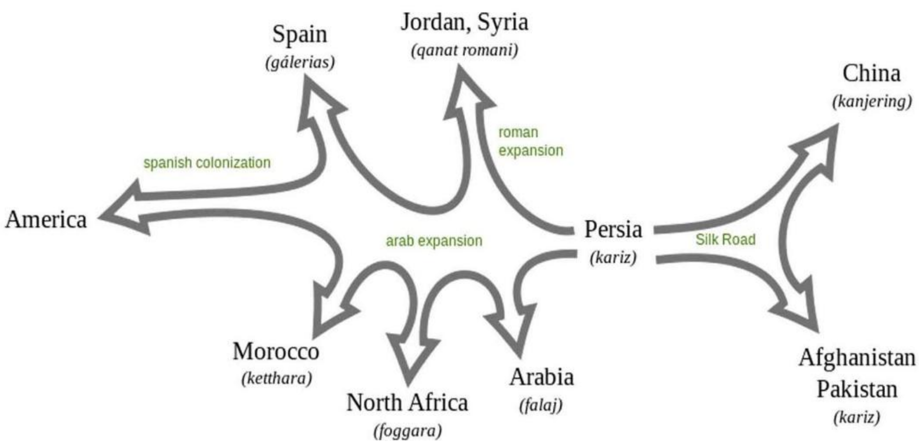

Fig. 2. The historical expansion of Qanats from Iran to other regions

In relation to the operation of qanats, after the qanat diggers (qanat workers) have confirmed the presence of water in the area and studied the specific conditions of the location, determining that the area is suitable for digging a qanat from every aspect, they begin the exploration operations. To ensure the presence of water, the qanat diggers undertake the drilling of exploratory wells in the water-bearing sections, and the number of these exploratory wells can reach up to three. With the use of buckets and simple tools, these skilled masters can estimate the water yield of the location. In the past, after this stage, the master worker would use surveying tools to determine the slope of the land and the distance from the exploratory wells to the qanat outlet, and then proceed to dig the mother well. The mother well is, in fact, the main source of nourishment for the qanat and is the part of the qanat that must produce and supply water throughout the year, making it particularly important. Mother wells are usually located in the water-bearing layers and are considered the deepest well among the series of vertical wells of the qanat. The method of digging mother wells is such that after drilling the exploratory wells and ensuring the presence of sufficient water resources and the existence of slope at the static level, they begin to dig the second exploratory well, which is the mother well. In fact, the mother well is the last well on the mountainside that leads to the underground channel and is considered the source of the qanat. The shafts are components of the qanat that are considered essential parts of it and apparently did not exist in the most primitive types of qanats. However, as the depth of horizontal wells continually increased to access more water, the issues of aeration and soil removal became more challenging, leading to the idea of creating shafts. The excavation of shafts in a qanat has four important and major uses. The first and most important benefit of these vertical wells is to provide air to individuals working deep underground. The second benefit of the shafts is related to when the qanat needs to be cleaned, which essentially serves to give the qanats a new life. The third benefit of the shafts is observed during the excavation of the water channel, where they play a crucial role in removing soil and rock resulting from the digging, saving time and energy. The last benefit of these wells is to guide the path of the qanat from above and control the direction of the channel. The depth of the shafts in a qanat starts from zero, which is the outlet and spring of the qanat, and reaches its maximum at the mother well located in the aquifer layers. The channel or conduit of the qanat is another component that is responsible for transporting water from the mother well to the spring of the qanat. This work also begins, like digging the shafts, from the spring and ends at the water sources. The method of operation is such that first, two adjacent shafts are excavated, and then the excavation of the channel is started from the downstream well and reaches the upstream well, progressing in this manner from the spring of the qanat to the dry areas. After ensuring the presence of water in the aquifer layers and drilling test boreholes, the first task is to determine the location of the spring, which is the point where the water emerges. The spring is usually located near a village or town so that the water can be easily used for people's needs, both for drinking water and agricultural purposes. The qanat, in fact, reaches the surface at the spring after traveling through its underground path, which is situated at various depths. To determine the location of the qanat spring, first, the depth of the mother well is measured, followed by the depth of the first test well, and then the slope of the ground surface and a slight slope that will be given to the underground channel are considered. Subsequently, the spring and the path of the underground channel are determined using a level and a compass. Another component of the qanat is the "haranj." The water from all qanats at all springs is not fully usable, meaning that sometimes there is a long distance from the qanat spring to where the water needs to be used. In this case, an open ditch or small channel is used to transfer water from the spring to the place of use. This open channel is called "haranj" or "haranj" (Sajadi, 1982). (Fig. 3) (Fig. 4)

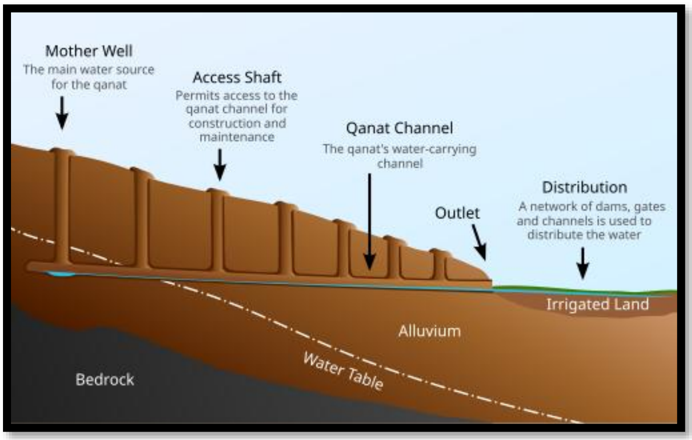

Fig. 3. Mechanism and components of a Qanat

Fig. 4. Hrang

The Qanats of Tabriz, which have existed since the Qajar era, have a similar structure. These Qanats include: Qanat Zobeideh, Qanat Hassan Padeshah, Qanat Shah Chalabi, Qanat Khwaja Ali Beik, Qanat Khwaja Qasim, Qanat Qurchi Bashi, Qanat Topchi Bashi, Qanat Hokmabad, Qanat Azizollah, Qanat Gazaran, Qanat Akbarabad, Qanat Mirza Ali, Qanat Marjan, Qanat Allahverdi Khan, Qanat Yengi Cheshmeh Shatervan, Qanat Cheshmeh Sheshgolan, Qanat Sanjaq, Qanat Haji Hassan Beik, Qanat Ahmad Pasha, Qanat Amir Nezam, Qanat Haji Jafar, Qanat Ilanlu, Qanat Montesh, Qanat Mirjalil, Qanat Sardar, Qanat Sharbaafan, Qanat Keshish, Qanat Koshk, Qanat Vazir, Qanat Ali Khatoon, Qanat Mir Qasim, Qanat Qazi, Qanat Imam Jom'e, Qanat Kucheh Bagh, Qanat Akhuni, Qanat Amir Aslan, Qanat Khan Mohammad Khan, Qanat Aqa Ali Akbar, Qanat Haji Mohsen, Qanat Tumas, Qanat Pahlavan, Qanat Heybat, Qanat Sultan Bozorg, Qanat Molla, Qanat Zaferanlu, Qanat Hoseyniyeh, Qanat Aqa Ali, Qanat Haji Mohammad Baqir, Qanat Haji Mirza Baqir, Qanat Kourjan, Qanat Vazirabad, Qanat Haji Abbas, Qanat Khatib, Qanat Molla Ali, Qanat Heydar Beig, Qanat Haji Mirza Hashim Agha, Qanat Fathabad, Qanat Shahzadeh, Qanat Haji Mirza Baqir, Qanat Nazem al-Tijar, Qanat Haji Saleh, Qanat Siraj, Qanat Baba Amin, Qanat Khatib, Qanat Mohammadiyeh, Qanat Qarasoo, Qanat Kreshkhuni, Qanat Haji Seyyed Hossein. The locations of some of the Qanats that are specified are drawn on the map of Dar al-Saltanah. (Fig. 5)

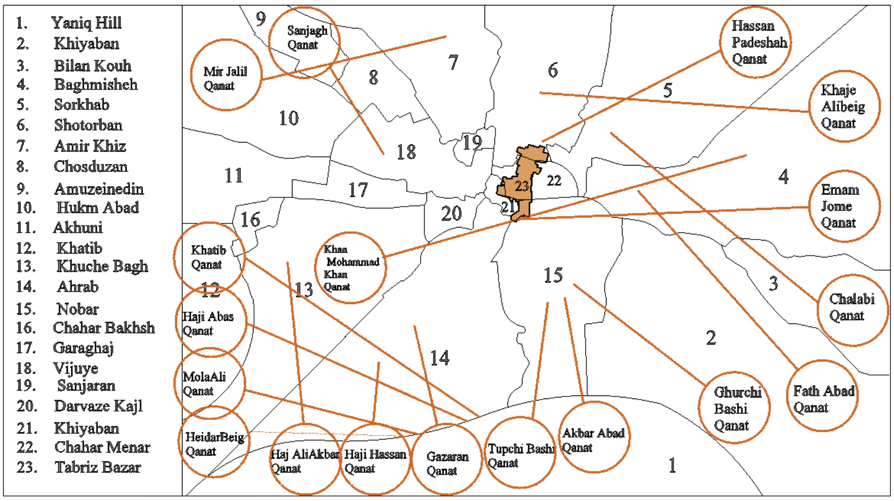

Fig. 5. Location of some Qanats on the map of Dar al-Saltaneh Tabriz

The use of qanats by people occurred in various ways, depending on the length of the qanat routes, the location of the water emergence or the spring of the qanats, and the residents along the route. Vegetable gardens, orchards, and similar places located downstream of the water spring of the qanats benefited from their water. Residents of neighborhoods situated along the qanat routes dug diagonally from the surface to the point where the water flowed underground to access drinking water, creating a staircase-like path that usually had a steep incline. They constructed the ceilings and walls of the tunnels with bricks so that people could easily access the water underground. The longer the distance from the source to the spring of the qanat, the greater the possibility of having multiple staircases (Hashemi, 2010). In addition, each qanat had a source in the center of the neighborhood, which had a water tap, and the residents of the neighborhood could use its water. (Fig. 6) (Fig. 7) (Fig. 8)

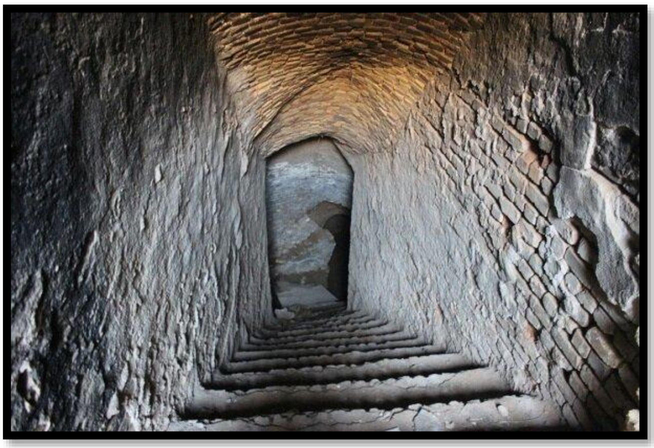

Fig.6. Outlet of Qanat in the center of the neighborhood Fig.7. A sample of the Forty-steps of a Qanat

Fig.8. The Outlet of the Qanat in the Gazaran neighborhood

The neighborhoods of the city of Tabriz each had a water master, whose duty was to channel the water from the streams and qanats using an "angaj" (a water distribution device, or in other words, a water distributor or divider) through the streets and yards to the homes. The angaj was a device made of a board with a thickness of five centimeters or more and of the required length and width. On this board, cutouts were made to meet the needs of each home and garden, and the water exiting from each cutout was directed to the specified home, yard, and garden (Hashemi, 2010). (Fig. 9)

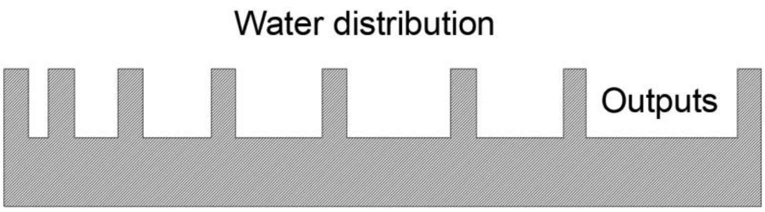

Fig.9. Angaj (Water distribution system)

The water distributors (Mirab) were involved in water distribution. Often, excess water was wasted. Water for drinking was distributed to citizens who had more financial means using buckets, which was usually done with a water skin or from a water source that was transported by carriage (Hashemi, 2010). (Fig. 10)

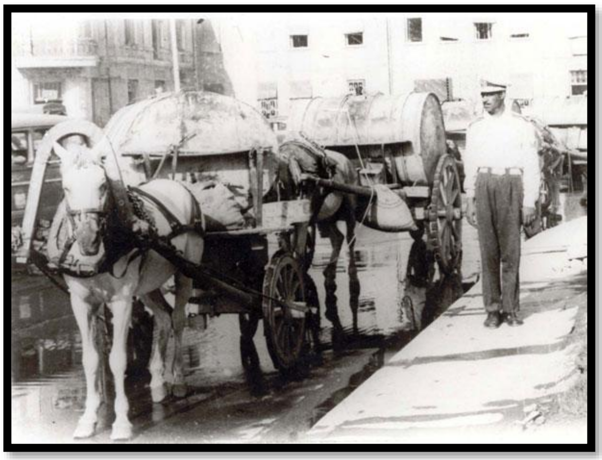

Fig.10. Mirab & Water transport Carriage in Tabriz city

3.2. Ab-Anbar (Water Storage)

A water reservoir has been a place for storing water. Due to the fact that the volume of water from qanats varies according to the seasons, and this volume is very high from Farvardin to Tir and experiences a decline starting in Mordad, by the end of the year, people have had to ensure a permanent water supply through reservoirs and ice houses. Two methods of passive cooling, aided by traditional architectural forms and local materials, have made it possible to store cold water and ice even in the hottest months of the year in the dry plains of central and eastern Iran. These cooling methods are carried out using energy resources available in the natural environment and are referred to as passive or self-sustaining methods. The architecture of water reservoirs in different regions has been so influenced by local architecture that they are recognized as part of the architectural identity of those areas. Specialists and experts in architecture, urban planning, history, and structures have categorized water reservoirs based on indicators such as functionality, efficiency, water intake capacity, the arrangement of stairways and other spaces, access to water, the shape of the tank and dome covering, construction methods, water supply methods and types, their specific locations in cities and neighborhoods, size, ventilation and cooling methods for water, as well as decorations, materials, into various styles and types. Water reservoirs are generally categorized into public, private (household), and a combination of public and private types. Public water reservoirs are typically large, impressive structures built by philanthropists, rulers, kings, and statesmen for the pleasure of God and the satisfaction of the people. The costs of construction, maintenance, water supply, repair, and restoration of these reservoirs were funded from public funds or endowment properties. Water reservoirs built in cities and villages on private properties for the benefit of the owners, their families, and members are called private reservoirs. These reservoirs or water tanks are mainly constructed in homes and sometimes in private gardens. Household reservoirs are generally made in three types: under courtyards, beneath buildings, or next to household wells. Courtyard reservoirs are built in cubic or rectangular shapes with flat or vaulted roofs, and access to them is possible through a bucket or pail. In these types of reservoirs, water is drawn through a hatch located in the roof or near the roof, or by using a hand pump connected to the tank. In reservoirs beneath buildings, access to water is achieved through a space called "pashir," which is level with the floor of the tank and is accessed using brass taps. The taps are placed slightly above the tank floor to prevent silt, mud, and other sediments from entering. In reservoirs near household wells, the water tanks are usually located above the building's foundation and close to deep wells. Thus, while providing drinking and household water, it has also contributed to the beautification of yards with ponds and fountains. The capacity of some of these cisterns was designed to supply the water needs of a household for three or four years. Some cisterns were used both publicly and privately. The water supply for the cisterns was sourced from rivers, rainwater, or manually. Rural, desert, and steppe cisterns were irrigated from river water, such that an inclined embankment was created in the riverbed to direct the water to a channel that connects to the cistern. Cisterns that were fed by rainwater fell into two categories: those that stored water collected from rooftops and those that collected rainwater from the ground surface. In the first type, the rooftops were constructed in such a way that rainwater would flow through a special downspout into the underground cistern. These cisterns have faucets and steps that are installed outside the tank. The second type of cisterns were desert cisterns built by humans in deserts but were filled with rainwater naturally (without human intervention). In manual cisterns, the structure of these cisterns is such that they do not fill with rainwater or river water (Dehgani, 2009), Rather, they are irrigated through human intervention, by transferring water from another location using well water, qanat, or spring. Sometimes, water must travel a distance of ten farsangs to reach the reservoir (Ayvaziyan, 1995). The method of accessing water has been through covered and open reservoirs. Covered reservoirs are dome-shaped or have a flat surface. These cisterns are very hygienic, and the water is ventilated and cooled by windcatchers, kheykhans, or openings in the ceiling. The main materials used in these cisterns are brick and mortar, but there are also types made of adobe and clay. A staircase is also located next to the reservoir leading to the pashir space. The use of water in these cisterns is not possible without access to the reservoir tap. Cisterns that have open reservoirs are also referred to as ponds or water cisterns. According to the definition by Master Bagban-zadeh: "A manual cistern means a cistern from which water is drawn by hand, either with the palm or with a bucket or container." These cisterns are built in two forms. In some of them, there is no water tap, and the staircase for drawing water is inside the reservoir, while in the other form of these cisterns, water is drawn using a rope, pulley, and bucket (water-lifter) (Dehgani, 2009). The appearance of water reservoirs is cylindrical, cubic, or hall-like. (Fig. 11)

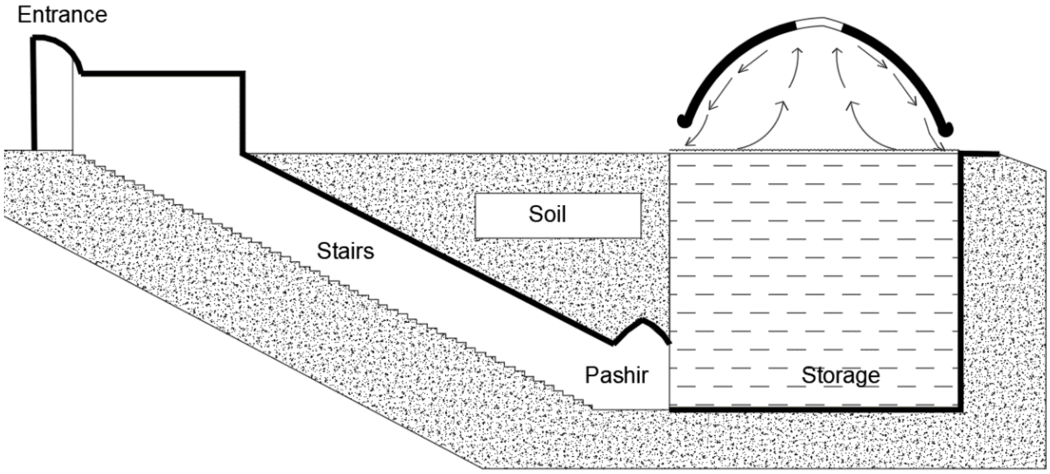

Fig.11. Ab-Anbar (Water Storage)

In the city of Tabriz, in some cases, the water from springs, qanats, or rivers was directed into water reservoirs to be used by the residents and inhabitants of different parts of the city. Additionally, there were private water reservoirs where individuals filled them based on their own resources from the water quota provided to them by the water overseers, using the water for drinking and other household purposes. The quotas were specified, and each neighborhood and family benefited from the amount of water measured by the angaj and separated from the main channels. Public water reservoirs were also filled with this water for public use. The water from some springs and qanats, which was very palatable, was distributed to people by water carriers using leather bags, or this type of water was sold in barrels on carts to wealthy families, with one rial paid for each bucket of water. The water that was stored stagnant in the reservoirs usually lost its quality, and often small red worms were found in the water reservoirs, prompting various methods to address the use of such water. People filled the reservoirs annually, and each year after complete emptying, the reservoirs were cleaned out, and necessary repairs were made to their walls and floors before being refilled with water. The situation in public water reservoirs was similar (Hashemi, 2010). For example, the cistern of the Selmasi House in Tabriz, which has now turned into a museum, is 8.4 meters long, 3.6 meters wide, and 4.8 meters high, and it was filled with water up to a height of about 3.8 meters, with a vent in the ceiling for ventilation. (Fig. 12)

Fig.12. Salmasi house's Ab-Anbar

3.3. Ice-House

Another phenomenon that has been used in people's lives as a complement to water reservoirs since the past is icehouses, which produced ice using passive cooling methods and taking advantage of the low temperatures at the threshold of freezing during the winter nights in the desert. The founders of this phenomenon, with their ingenuity and the use of simple architectural elements, created a collection of icehouses on the outskirts of villages and towns (Dehgani, 2009). In many warm regions of Iran, storage facilities such as ice houses were built to keep ice for the hot days of the year. Ice houses and water reservoirs are two superior skills of the Iranians (Jorgensen, 2012). These ice houses had a tall wall beside them, referred to as the "shade wall." In the shade of this wall, there were shallow water catchments where water was poured during cold weather to freeze into ice. The tall wall prevented the ice from melting during the day. To fill the catchments with water during the cold winter months, water was directed to the channels beside the catchments in the morning, and workers would sprinkle the water onto the catchment with shovels. Since the weather was cold, a thin layer of water would freeze. Then, water would be sprinkled on top again, making this layer thicker. This process was continued as needed. The ice was then broken into pieces and thrown into the ice house to prevent the pieces from sticking together. Finally, the entrance was sealed, and the ice was stored for the summer (Rafie Sereshki et al., 2004). The construction of icehouses is not particularly complex. The main components of an icehouse include the main shade wall, the secondary shade wall, ice production pools, the icehouse storage structure, a warehouse, an ice keeper's room, and an entrance; however, not all of these components exist in every icehouse, nor are they all the same (Papeli Yazdi & Labbaf Khaniki, 1999). In the city of Tabriz, like in other cities of Iran, several icehouses remain, one of which is the icehouse located on United Nations Street in Tabriz, which is at risk of destruction. (Fig. 13)

Fig.13. Sample of a Ice-House on United Nations street in Tabriz

3.4. Sardabeh

In the traditional architecture of the dry regions of Iran, spaces were constructed within the earth for specific and defined purposes, generally referred to as "underground." A Sardab is a type of underground space built in proximity to water. In some sar-dabs, traditional architects raised the height above ground level to bring light into the space, while in others, which were completely sunken and did not protrude above the courtyard, different methods were employed to bring light inside, such as using marble in the courtyard floor. Traditional craftsmen used bricks to pave the floor of the sar-dab. Initially, the bricks were laid dry, and then a mixture of clay and lime was poured into the joints, or a layer of clay and lime was applied over them. The ceiling of the Sardab was generally constructed using techniques such as barrel vaults, Roman arches, and elephantine arches. The materials used in the ceiling of the Sardab were mostly bricks, and if adobe was also used, the underlying layer was covered with bricks. The forces exerted from the ceiling are broken down into horizontal and vertical components and transferred to the ground by the walls. At first glance, the decorations of the Sardabs may seem very simple, but upon closer inspection, niches can be seen that are adorned with bricks and plaster, creating numerous visual beauties. The niches served as storage spaces for household items, and their height from the ground was determined based on the height of adults for placing or retrieving household items. Additionally, the niches played an important role in reducing the mass and weight of the walls, as well as saving materials and costs. The entrances to the Sardabs were often located in the corners of the courtyard, guiding people inside with spiral stairs. In fact, going underground is a way to achieve thermal balance in the environment. The conditions for a cellar located at a depth of less than six meters are different; the air temperature inside the cellar depends on the stable ground temperature at the average depth of the cellar and the outside air temperature. Throughout the different seasons of the year, the temperature of the cellar changes with the variations in outside air temperature. In the spring and summer, the temperature of the cellar is optimal and remains almost constant, with the influence of stable ground temperature on the cellar temperature being greater than the variations in outside temperature. In the fall and winter, the cellar temperature is more affected by outside temperature changes; during these seasons, the cellar temperature drops, and the influence of ground temperature decreases due to increased natural ventilation, while the influence of outside air temperature increases (R. Mazarron & Canas, 2009). (Fig. 14)

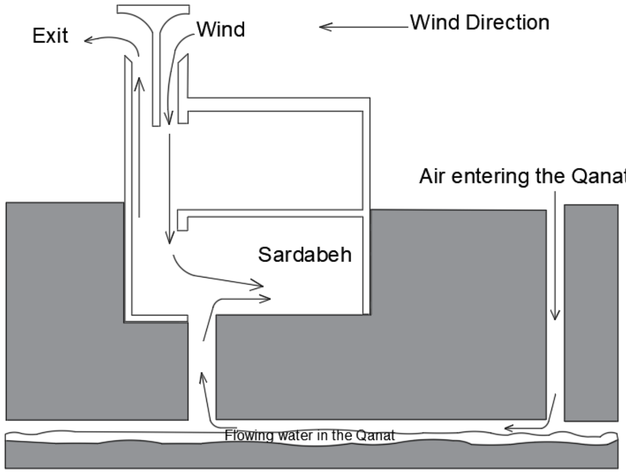

Fig.14. Sardabe (Kind of Basement)

3.5. Hozkhaneh

The poolhouse is a summer space and usually has an octagonal shape. In the middle of this space, a small pool is built, which typically has an octagonal shape, and the reason for its naming is due to the presence of this pool in the space. The presence of cool water in this area moistens and reduces the air temperature on hot summer days. The poolhouse is an enclosed space that receives light from the ceiling, and in some poolhouses, a tall windcatcher is constructed to bring cool air into the interior of the poolhouse. The operational system of the poolhouse works such that the spraying of water by the fountain cools the environment (Zangane, 2011). The water for the fountains is usually supplied by a qanat. The qanat water is transferred from the source through clay pipes to below the poolhouse and enters the pool through the fountains. (Fig. 15)

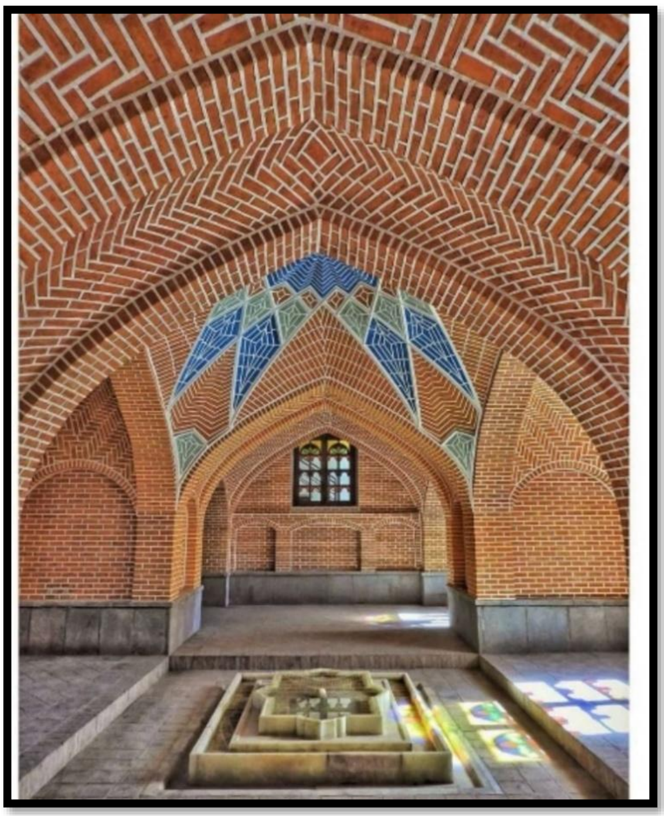

Fig.15. Sedqiani's pond in Tabriz

4. Conclusions

In ancient times, with the expansion of qanats, which were essentially the main source of water supply for other related structures, the needs of humans for water and associated issues were well addressed. In Iran, this method of water supply dates back three thousand years; however, it is still one of the significant water sources in the central and eastern cities. Yet, since Azerbaijan is the birthplace of qanats and the site of their emergence, out of the hundreds of qanats present, only a limited number are active and in use. In addition to qanats, other structures such as ice houses, water reservoirs, and cold storages in the city of Tabriz are also at risk of destruction. This article aims to take a small step in expressing the importance of these structures in supplying water to the city of Tabriz by examining how they function. According to Henri Goblot, qanats are underground tunnels for draining deep waters, with their endpoints revealed by openings. He states that a qanat is a method for obtaining or delivering water, a technique with mineral characteristics that makes the exploitation of groundwater possible through drained tunnels. Since the aquifers in the city of Tabriz still exist, this structure can be revived and used. Other structures examined in this article share the same conditions; for example, there are large water reservoirs and ice houses throughout the city that can be restored and made usable again with rehabilitation and major repairs.

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Potential of using agricultural wastes as thermal insulation material: The case of wheat straw insulation on external walls

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Abstract. Climate change has become a critical problem globally. In this context, it has become inevitable to enhance the environmental performance of buildings in the construction sector, which consumes the most energy and causes the most carbon emissions. Thermal insulation materials play a crucial role in reducing the energy requirement for heating and cooling of buildings by improving their thermal performance. Currently, inorganic materials constitute the majority of thermal insulation materials utilized in the construction sector. Despite these materials' excellent heat transmission properties, their manufacturing processes are highly energy-intensive, resulting in considerable carbon emissions. However, bio-based thermal insulation materials can replace conventional thermal insulation materials used in buildings due to their exceptional thermal performance and low carbon emissions.

In Türkiye, expanded polystyrene (EPS), extruded polystyrene (XPS), rockwool (RW), glasswool (GW), and polyurethane (PUR) are commonly used thermal insulation materials in buildings. This research aims to interpret whether using bio-based thermal insulation materials as an alternative to conventional thermal insulation materials will increase the energy efficiency of buildings in Türkiye, a country rich in biomass. Within the scope of this research, wheat straw (WS), which has the highest amount of agricultural waste in Türkiye, was selected for the case study. The effect of using wheat agricultural waste as a thermal insulation material on the buildings' external wall systems on the thermal performance was assessed through energy simulations using the OpenStudio and EnergyPlus building energy modeling tools. In line with the obtained data, the usability of agricultural wastes as thermal insulation material, alternatively to conventional insulation materials commonly used in Türkiye, was evaluated.

Keywords: Climate change; Energy efficiency; Agricultural waste; Innovative building materials; Bio-based thermal insulation materials

1. Introduction

The climate change problem has been one of the most significant environmental threats in recent years. Increasing global industrialization and excessive use of fossil fuels have led to rapid consumption of energy resources and increased global temperatures due to greenhouse gas emissions, triggering environmental problems (Chen et al., 2022). The building sector was responsible for 32% of global energy consumption and 34% of global carbon emissions in 2024 (United Nations Environment Programme & Global Alliance for Buildings and Construction, 2025). Likewise, in Türkiye, the building sector is the largest energy-consuming sector, accounting for 30% of total energy consumption in 2023 (Ministry of Energy and Natural Resources of Türkiye, 2024). To cope with the problem of increasing energy demand and rapid depletion of energy resources, reducing external dependency on energy, using alternative energy sources, and increasing energy efficiency have become inevitable necessities in the building sector.

50–60% of heat gain and loss in the building occurs through the building envelope; therefore, building envelope insulation is crucial for energy-efficient buildings (Kumar et al., 2020). Conventional insulation materials, currently used in building envelopes, contribute to reducing energy consumption in buildings due to their low thermal conductivity values. However, their manufacturing process requires high energy since they contain mineral and fossil-based materials. Therefore, in addition to the thermal performance of insulation materials, their life cycle should also be considered, and the use of environmentally friendly insulation materials produced using renewable resources should be considered (Ajabli et al., 2023). In this context, bio-based insulation materials stand

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out as clean and energy-efficient alternatives that reduce energy use and greenhouse gas emissions (Rabbat et al., 2022). In addition, bio-based insulation materials have significant potential to improve buildings' thermal performance and promote sustainability in the construction industry (Cosentino et al., 2023). Insulations based on agricultural waste can be an alternative to existing insulation materials in reducing environmental impacts, depending on the sustainability of their production processes (Palumbo et al., 2015). Moreover, insulation materials obtained from straw, a local agricultural waste product, have attracted significant attention as promising insulation materials in this field due to their high hygrothermal performance, low life cycle cost, and low carbon footprint features (Zhou et al., 2022).

In 2023, over 220.7 million hectares of wheat were grown worldwide, and 808.4 million tonnes of wheat were produced. Furthermore, Türkiye became the ninth-largest wheat-producing country in the world, with a wheat production of 22 million tonnes this year (Food and Agriculture Organization of the United Nations, 2024). In addition, Türkiye, which stands out with its cereal production, has agricultural lands that constitute 30.4% of its land, and the most abundant agricultural product is wheat in Türkiye. Therefore, a significant amount of wheat waste is generated yearly (Cakal & Celik, 2022). However, agricultural waste is not evaluated sufficiently in Türkiye, and wheat, which creates a significant amount of waste after harvest, is commonly used as animal feed (Unlu et al., 2023).

The primary purpose of this study is to evaluate the feasibility of using agricultural waste as insulation material in the building industry in Türkiye, which is rich in biomass. Within the scope of the study, the usability of wheat straw (WS) as an alternative to conventional insulation materials (EPS, XPS, RW, GW, and PUR) widely used in Türkiye was evaluated by comparing their thermal performances. In this context, the thermal performance of different insulation materials in various climatic conditions of Türkiye was examined in terms of their use in buildings' external walls.

2. Materials and Methods

The study consists of five main steps: definition of the sample building and different building external wall system insulation scenarios, selection of the cities, determination of the minimum insulation thickness to use according to different climatic conditions, performing energy modeling of the defined scenarios, and evaluating the results (Fig. 1).

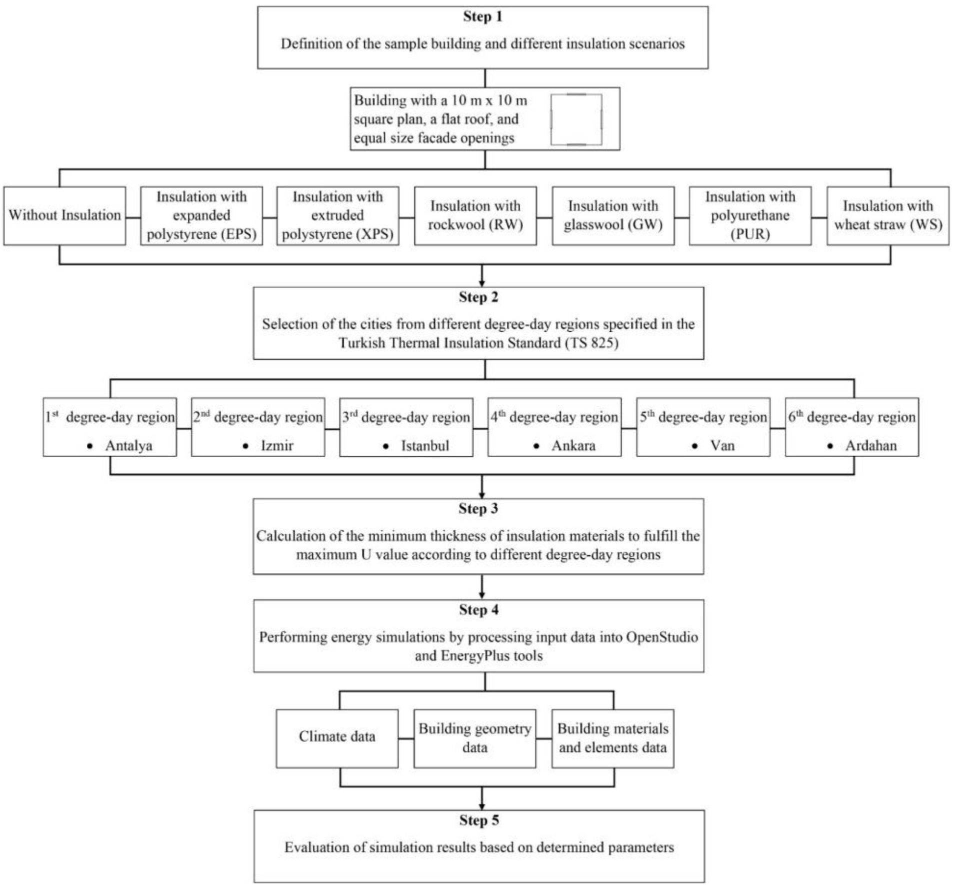


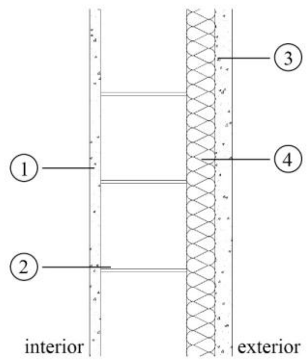
Fig. 1. The research design framework

This study applied the methodology to a typical building with a 10 m x 10 m square plan, a flat roof, and equal openings on all facades. In the study, the external wall system of the building envelope was included in the scope for the thermal performance evaluation of the insulation materials (Table 1). The thermal performance of the external walls was evaluated according to scenarios where there was no insulation, and different insulation materials were used. The thermal transmittance behavior of the external walls was evaluated by energy simulations considering different climatic conditions and facade orientations. The building geometry, layer structure of the building elements, physical properties of the building materials, and climate data inputs were processed using the OpenStudio building energy modeling software. The process of obtaining energy simulation results was carried out by using the OpenStudio and EnergyPlus tools simultaneously. As a result of the energy simulations, the thermal performances of the external wall components were analyzed based on the internal and external surface temperatures.

According to the TS 825 standard, Türkiye has six climatic zones (Fig. 2). The regions representing the climate zones are determined according to the average temperature degree and heating days and are called degree-day regions. The temperatures of the climate zones decrease from the first-degree-day zone to the sixth-degree-day zone (Turkish Standard Institution, 2024). The research was conducted by selecting one city from each climate zone. Antalya, Izmir, Istanbul, Ankara, Van, and Ardahan constitute the cities of the case study. While performing energy simulations, weather data belonging to these cities were used.

In the study's first phase, the minimum insulation thicknesses required by climatic zones for different insulation materials were calculated based on the TS 825 standard, which defines different climate conditions in Türkiye. The calculations aimed to present the combination of materials and minimum insulation thicknesses that fulfill the energy performance requirements according to different climatic zones. For this purpose, the heat transfer coefficients (U values, W/m^{2}K) of external wall systems were fixed to the maximum possible value foreseen by the TS 825 standard for each climatic zone (Table 2).

Table 1. External wall system design of the sample building

Building external wall system	Layers	Thickness (m)	Thermal conductivity (W/mK)	Density (kg/m^3)
	1-Cement-based interior plaster	0.02	1.0*	1800*
	2-Aerated concrete block	0.15	0.2025*	637.5*
	3-Insulation material			
	• EPS	-	0.0375*	20*
	• XPS	-	0.035*	25*
	• RW	-	0.0425*	254*
	• GW	-	0.0425*	254*
	• PUR	-	0.0325*	30*
	• WS	-	0.06[a]	94[b]
	4-Cement-based exterior plaster	0.03	1.0*	

*Average of specified values in the TS 825 standard (Turkish Standard Institution, 2024)

[a]Average of values in the literature: 0.0465 (Mehravar et al., 2022), 0.0573 (Cascone et al., 2019), 0.0465 (Rojas et al., 2019), 0.0726 (Costes aet al., 2017), 0.0504 (Reif et al., 2016), 0.07 (Conti et al., 2016), 0.0622 (Shea et al., 2013), and 0.0745 (Ashour, 2003).

[b]Average of values in the literature: 61 (Mehravar et al., 2022), 77.98 (Cascone et al., 2019), 109.523 (Rojas et al., 2019), 104.635 (Costes et al., 2017), 108.333 (Reif et al., 2016), 84.11 (Conti et al., 2016), 95.116 (Shea et al., 2013), and 110.6 (Ashour, 2003).

Fig. 2. Climate zones of Türkiye according to TS 825: 2024 (Association of Heat, Water, Sound and Fire Insulators, 2025)

Table 2. Recommended maximum U values for walls according to TS 825:2024

Climate zone (degree-day region)	Selected city	U value requirement for walls (W/m^2K)
1	Antalya	0.45
2	Izmir	0.4
3	Istanbul	0.4
4	Ankara	0.35
5	Van	0.25
6	Ardahan	0.25

Table 3. Minimum insulation thicknesses according to the U-value requirements of selected cities

	Minimum EPS thickness (m)	Minimum XPS thickness (m)	Minimum RW thickness (m)	Minimum GW thickness (m)	Minimum PUR thickness (m)	Minimum WS thickness (m)
Antalya	0.05	0.045	0.055	0.055	0.045	0.08
Izmir	0.06	0.055	0.07	0.07	0.055	0.095
Istanbul	0.06	0.055	0.07	0.07	0.055	0.095
Ankara	0.075	0.07	0.085	0.085	0.065	0.115
Van	0.115	0.11	0.13	0.13	0.1	0.185
Ardahan	0.115	0.11	0.13	0.13	0.1	0.185

The insulation thickness calculations that will meet the U value requirement were found through the Eq.(1) established with the internal surface thermal resistance (R_i), the total resistance of other materials in the wall layer (R_w), the thermal resistance of the insulation material (x_{ins}/k_{ins}) and the external surface thermal resistance (Ucar & Balo, 2009). The thermal conductivity coefficients (k, W/mK) of EPS, XPS, RW, GW, and PUR insulation materials were obtained from the average values specified in the TS 825 standard. For WS, the average of the thermal conductivity coefficients (k, W/mK) obtained from the literature was taken (Table 1).

$$U = \frac{1}{R_i + Rw + \frac{x_{ins}}{k_{ins}} + R_o} \quad (1)$$

The calculations revealed the minimum insulation thicknesses that meet the maximum U value limits for cities selected from different climate zones (Table 3). The thickness data revealed that wheat straw (WS) insulation required more thickness in all regions to fulfill the U-value requirements due to its higher thermal conductivity coefficient than other insulation materials. While the thickness values of conventional insulation materials ranged from 0.045 m to 0.13 m from the first-degree-day region to the sixth-degree-day region, the thickness values of wheat straw (WS) insulation ranged from 0.08 m to 0.185 m.

In the study's second phase, the data obtained were processed using OpenStudio software to create an energy model for the sample building. When developing the energy model, external weather conditions specific to the selected cities were considered. During the energy modeling phase, the building properties were kept constant, while simulations were conducted by varying the insulation material properties and weather data for different insulation scenarios and cities.

In the final phase, the energy models created were transferred to EnergyPlus software to obtain simulation results. This approach allowed for a comprehensive evaluation of how insulation materials that fulfill the U-value requirement for different climatic zones impact the building's thermal performance. In line with the simulation results, evaluations were made on the data regarding the inside and outside surface temperatures of external walls.

3. Results and discussion

In this study, the heat transfer behavior of external wall components constructed with no insulation and different insulation materials was examined seasonally according to cities and facades. The inside and outside surface temperature values of the external wall components were used to evaluate the effectiveness and thermal performance of the insulation material. The difference between the external wall systems' inside and outside surface temperatures directly revealed the extent to which the insulation materials prevented heat transfer. Since the thicknesses of the insulation materials were determined to fulfill the same U-value requirement, the heat transfer behavior of the wall components was similar in the insulated scenarios, even if the material type changed. Therefore, identical inside and outside surface temperatures occurred in the wall systems formed with different insulation materials. However, the inside surface temperatures were generally higher in the insulated scenarios than the uninsulated ones. This situation revealed that the insulation materials effectively provided indoor comfort.

The first finding is the thermal transmittance behavior of the external walls of a building in Antalya, which were designed with no insulation and different insulation materials according to months and facades. As can be seen from Fig.3,

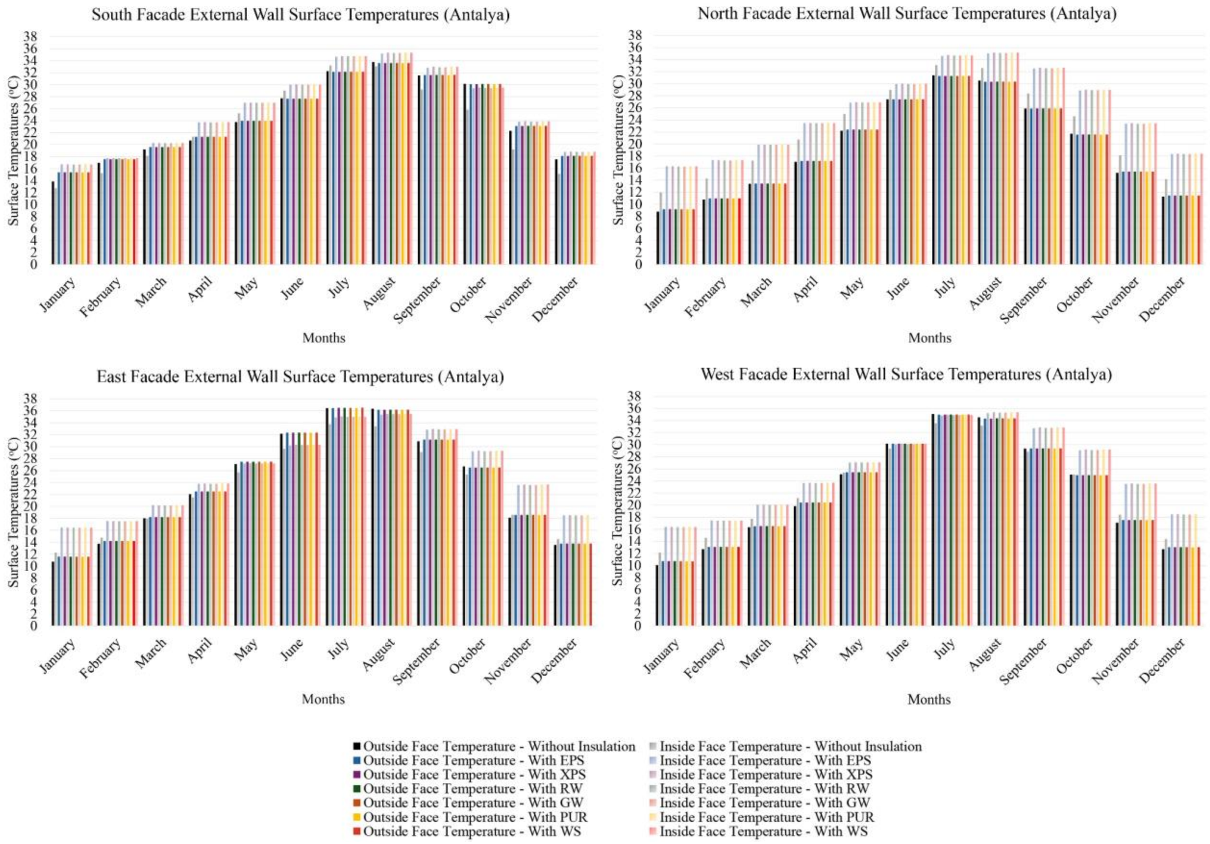


Fig. 3. Inside and outside surface temperatures of external wall systems of a building in Antalya according to facades and months.

- In the summer months, the average inside surface temperatures of uninsulated walls were observed to be 30.6 °C on the south facade, 29.3°C on the north facade, 34.6 °C on the east facade, and 33°C on the west facade. Despite the intense solar radiation and natural heating that showed its effect on all facades in Antalya in the summer months, the inside surface temperature did not tend to increase excessively. This result indicates that the insulation materials exhibited a positive performance since they limit the transfer of excessively hot air from the outside to the inside surfaces of the walls to a certain extent.
- In addition, in the south facade, which receives the most heat in the winter months, the outside surface temperatures reached 18°C. On the other facades, where the direct solar radiation is less seen, the highest outside surface temperature in winter was 14°C. On the other hand, the inside surface temperature of all facades in uninsulated walls dropped to 12°C, while it increased to 18°C in insulated walls. This result shows that even if the outside surface temperature is low on facades where the solar radiation effect is less visible, the insulation materials are not directly affected by the outdoor temperature decrease and show good effectiveness.
- Due to the sun's exposure effect on the facades, the outside surface temperature on the east, south, and west facades was higher than that of the north facade throughout the year. However, although the outside surface temperature decreased on the north facade, the inside surface temperatures on the insulated walls remained high. This result shows that the insulation materials prevent the cold air from passing from the outside to the inside and are effective.
- Wheat straw (WS) insulation, when used at a thickness of 0.08 m in the cities of the first-degree-day region, exhibits similar thermal transmittance behavior to conventional insulation materials in different months and on various building facades.

The second finding is the thermal transmittance behavior of the external walls of a building in Izmir, which were designed with no insulation and different insulation materials according to months and facades. As can be seen from Fig.4,

- In the summer months, the average inside surface temperatures of uninsulated walls were measured as 31.3°C on the south facade, 30.6°C on the north, 29.3°C on the east, and 31.3°C on the west facade. In the insulated cases, inside surface temperatures were fixed at approximately 33°C on all facades. This result shows that insulating materials effectively limit the temperature increase rather than reduce the interior temperature in absolute terms on facades heated by intense solar radiation in the summer.

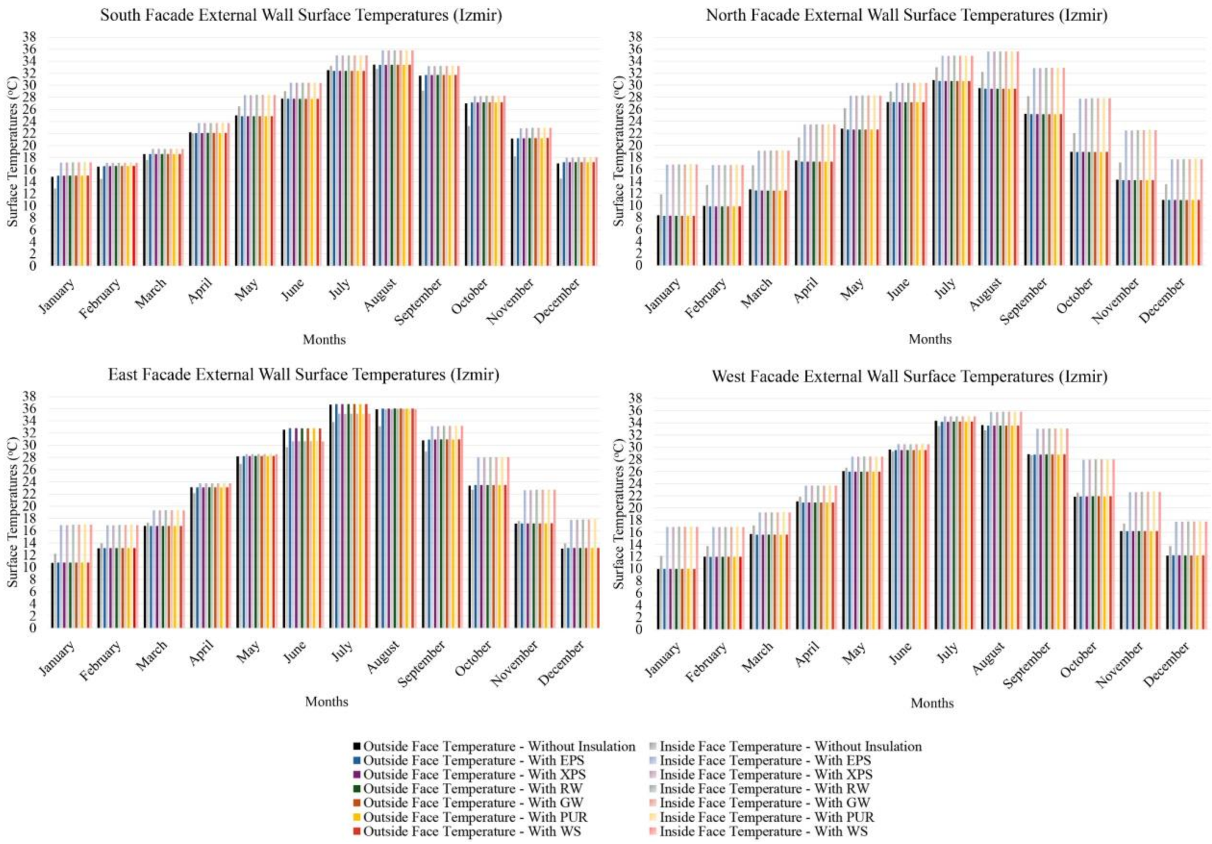


Fig. 4. Inside and outside surface temperatures of external wall systems of a building in Izmir according to facades and months.

- In winter months, uninsulated walls exhibited low interior surface temperatures on all facades. When the average temperature values were examined, inside surface temperatures of 13.3°C were recorded on the south facade, 12.3°C on the north facade, 12.6°C on the east facade, and 12.6°C on the west facade in uninsulated walls. In the insulated scenarios, inside surface temperatures increased significantly in all insulation material types in the winter months, reaching approximately 16–16.3°C. Especially on the north facade, where solar radiation is limited, the effect of insulation became apparent, and the inside surface temperature increased by approximately 4°C compared to the uninsulated situation.
- Wheat straw (WS) insulation, when used at a thickness of 0.095 m in the cities of the second-degree-day region, exhibits similar thermal transmittance behavior to conventional insulation materials in different months and on various building facades.

The third finding is the thermal transmittance behavior of the external walls of a building in Istanbul, which were designed with no insulation and different insulation materials according to months and facades. As can be seen from Fig.5,

- In the summer months, the average inside surface temperatures of uninsulated walls were observed to be 27.3°C on the south facade, 27.3°C on the north facade, 28.3°C on the east facade, and 28°C on the west facade. When insulated scenarios are examined, inside surface temperatures on all facades increased to approximately 30°C. This result shows that in the cooler summer conditions of Istanbul compared to previous case cities, insulation helps limit daily temperature changes by reducing thermal emissions rather than absolute temperatures. On the east and west facades, the effect of insulation materials against temperature increases caused by direct solar radiation in the morning and afternoon was partially limited; however, they prevented overheating in inside surface temperatures.
- In winter months, uninsulated walls showed lower inside surface temperatures. When the average temperature values were examined, inside surface temperatures were measured as 11.6°C on the south facade, 11°C on the north facade, 11°C on the east facade and 11°C on the west facade. In the scenarios where insulation was applied, all insulation materials showed similar performance, increasing inside surface temperatures to an average of 14.5°C in winter months. Insulation materials exhibited similar thermal transmittance behavior on the north facade, where solar radiation was limited, and on other facades where solar radiation was more dominant, and showed positive effectiveness in increasing inside surface temperatures.

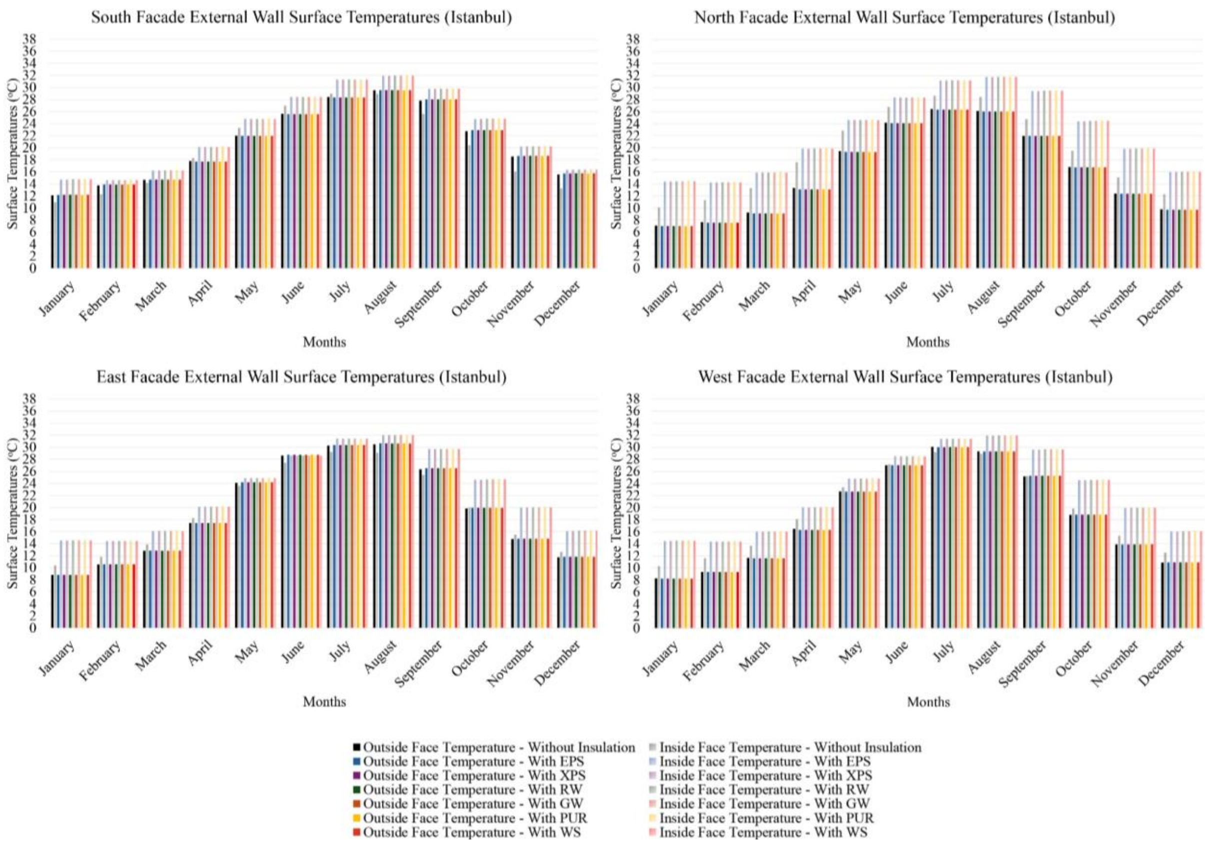


Fig. 5. Inside and outside surface temperatures of external wall systems of a building in Istanbul according to facades and months.

- Wheat straw (WS) insulation, when used at a thickness of 0.095 m in the cities of the third-degree-day region, exhibits similar thermal transmittance behavior to conventional insulation materials in different months and on various building facades.

The fourth finding is the thermal transmittance behavior of the external walls of a building in Ankara, which were designed with no insulation and different insulation materials according to months and facades. As can be seen from Fig.6,

- In the summer months, the average inside surface temperature of uninsulated walls was observed as 27°C on the south facade, 27°C on the north facade, 27.6°C on the east facade, and 27.3°C on the west facade. The average inside surface temperature in the insulated scenarios was 29.5°C on all facades. This result reveals that insulation materials tend to keep the inside surface temperature constant at a specific temperature by protecting it from overheating rather than reducing it in the summer months.
- In the winter months, especially on the north facade, where the sun's effect is low, the inside surface temperatures remained high even though the outside surface temperature of the walls was very low. The temperature difference between the insulated walls' outside and inside surfaces reached 9°C on the north facade. This situation reveals that the insulated walls prevent the low exterior surface temperature transfer to the interior surface and show good thermal performance.
- Furthermore, in winter, the average inside surface temperature of uninsulated walls was observed as 8°C on the south facade, 7°C on the north facade, and 7.3 °C on the east and west facades. In the insulated scenarios, the average inside surface temperature of the walls was observed as 12.3°C on the south facade, 11.3°C on the north facade, and 12°C on the east and west facades. This result shows that the insulation materials contributed an average of 4.5°C to the increase in the inside surface temperature on all facades. A similar thermal transmittance behavior was observed on the east and west facades in all insulation scenarios. Although natural solar radiation was effective on these facades in winter months, the insulation materials significantly increased the inside surface temperature.
- Wheat straw (WS) insulation, when used at a thickness of 0.115 m in the cities of the fourth-degree-day region, exhibits similar thermal transmittance behavior to conventional insulation materials in different months and on various building facades.

The fifth finding is the thermal transmittance behavior of the external walls of a building in Van, which were designed with no insulation and different insulation materials according to months and facades. As can be seen from Fig.7,

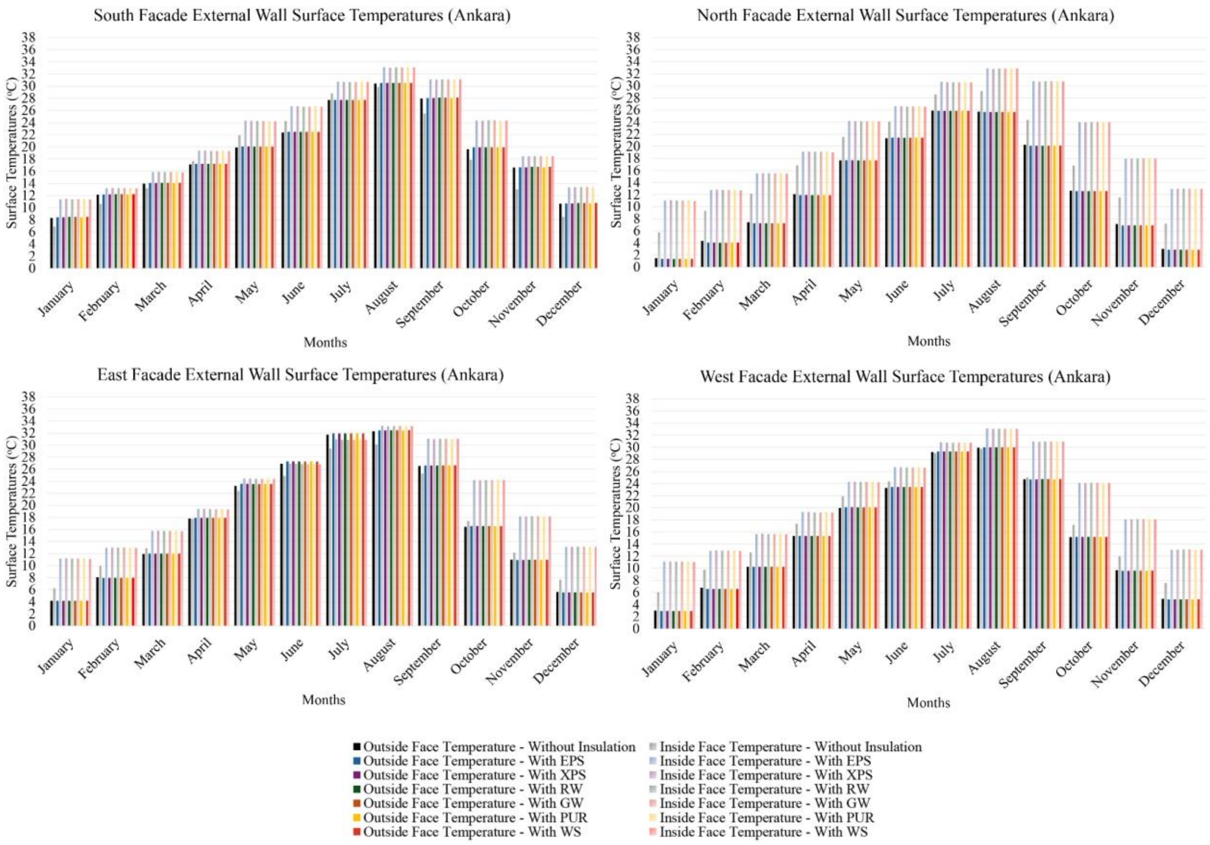


Fig. 6. Inside and outside surface temperatures of external wall systems of a building in Ankara according to facades and months.

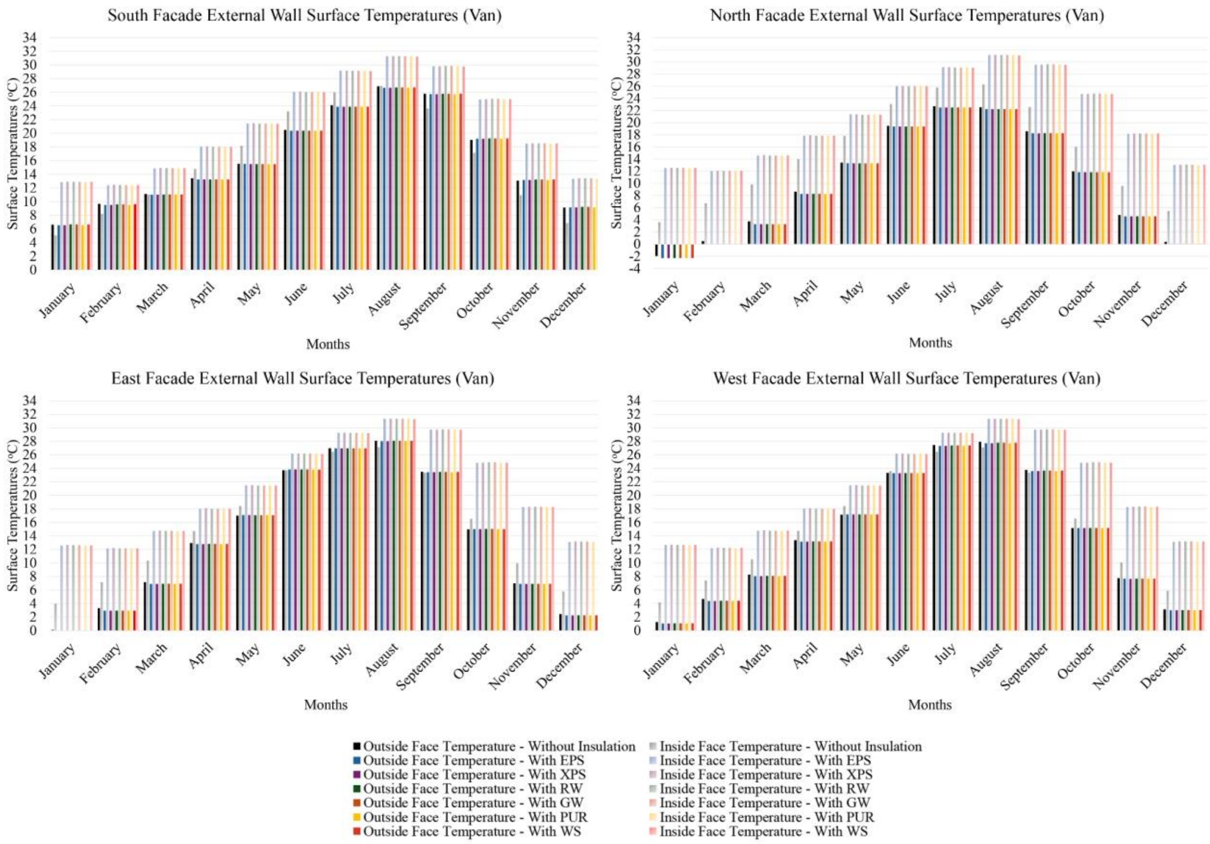


Fig. 7. Inside and outside surface temperatures of external wall systems of a building in Van according to facades and months.

- In the summer months, the average inside surface temperatures of uninsulated walls were measured as 25.3°C on the south, east, and west facades and 24.6°C on the north facades. In insulated cases, the inside surface temperatures were fixed at approximately 28.6°C on all facades. This situation shows that in insulated scenarios, insulation materials slightly increase the temperature on the inside surface but keep it constant after a certain degree.
- In winter months, a significant difference was observed between the outside surface temperatures and the inside surface temperatures of the insulated walls. This effect was most dominant on the north facade, where the sun's effect was the least. While the outside surface temperatures on the north facade dropped to an average of -0.6°C, the inside surface temperatures on all insulated walls remained constant at an average of 12.3°C. The 12°C difference between the outside and inside surfaces shows that the insulation effectively limits the cold air transfer from the outside environment and provides good thermal performance.
- Moreover, in winter, the average inside surface temperature of uninsulated walls was observed as 6.3°C on the south facade, 4.6°C on the north facade, and 5 °C on the east and 5.3 °C on the west facade. In the insulated scenarios, the average inside surface temperature of the walls was observed as 12.3°C on all facades. This result shows that the insulation materials contributed an average of 6-7°C to the increase in the inside surface temperature on all facades.
- Wheat straw (WS) insulation, when used at a thickness of 0.185 m in the cities of the fifth-degree-day region, exhibits similar thermal transmittance behavior to conventional insulation materials in different months and on various building facades.

The final finding is the thermal transmittance behavior of the external walls of a building in Ardahan, which were designed with no insulation and different insulation materials according to months and facades. As can be seen from Fig.8,

- In the summer months, the average inside surface temperatures of uninsulated walls were measured as 22.6 °C on the south, east, and west facades and 22 °C on the north facades. In insulated cases, the inside surface temperatures were fixed at approximately 25°C on all facades. This result shows that the insulation materials provide a slight temperature increase in the inside surface temperatures of all facades; however, they keep the inside surface constant at a specific temperature by protecting it from temperature fluctuations.

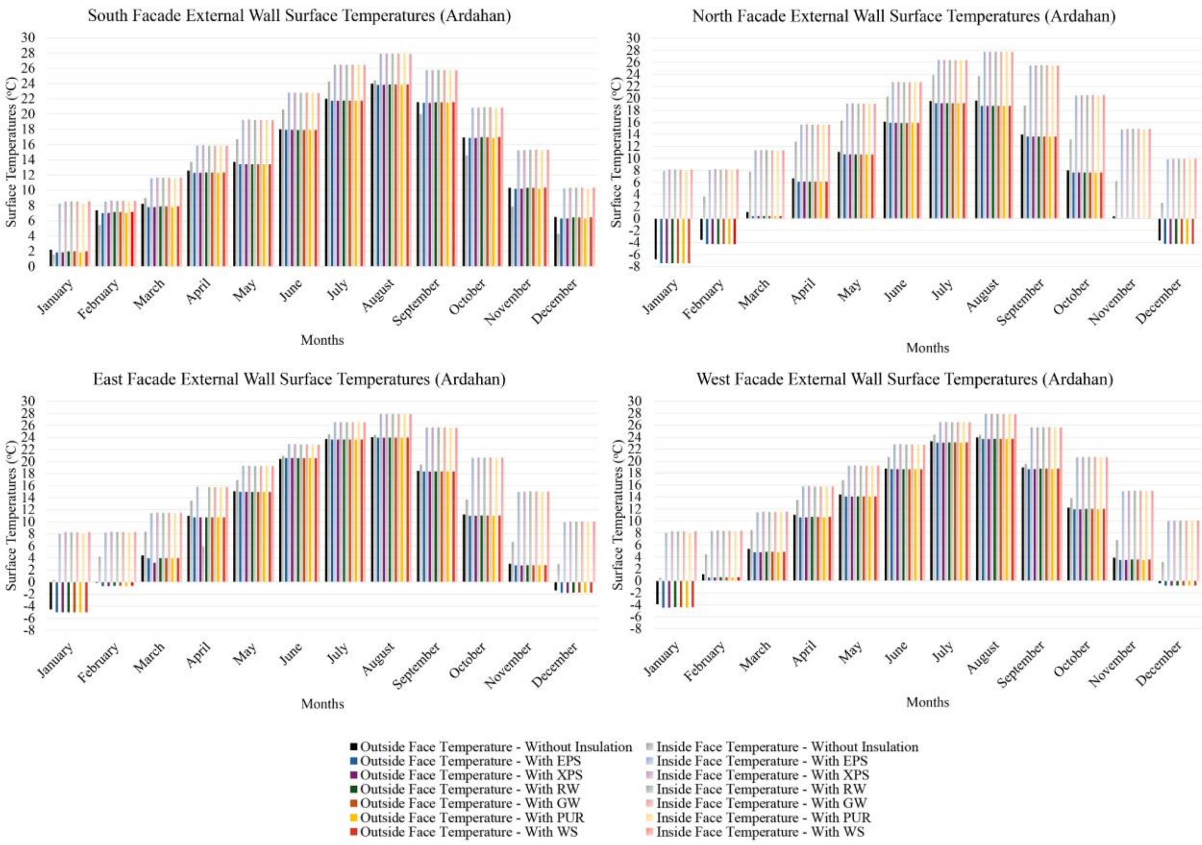


Fig. 8. Inside and outside surface temperatures of external wall systems of a building in Ardahan according to facades and months.

- In winter months, a significant difference was observed between the insulated walls' outside and inside surface temperatures, similar to Ankara and Van. While the outside surface temperatures on the north facade dropped to an average of -5 °C, the inside surface temperatures on all insulated walls remained constant at an average of 8°C. The 13°C difference between the outside and inside surfaces shows that the insulation effectively limits the cold air transfer from the outside environment and provides good thermal performance.
- Furthermore, in winter, the average inside surface temperature of uninsulated walls was observed as 3.3°C on the south facade, -4°C on the north facade, and -1.6°C on the east and -1°C on the west facade. In the insulated scenarios, the average inside surface temperature of the walls was observed as 8.6 °C on the south and west facades and 8°C on the north and east facades. This result shows that the insulation materials increased the inside surface temperature on all facades. For this reason, all insulation materials exhibited the same behavior in heat conductivity despite cold climatic conditions.
- Wheat straw (WS) insulation, when used at a thickness of 0.185 m in the cities of the sixth-degree-day region, exhibits similar thermal transmittance behavior to conventional insulation materials in different months and on various building facades.

4. Conclusions

In conclusion, the study revealed that agricultural waste has the potential to be used as an insulation material in a country like Türkiye, which is rich in agricultural waste. Expanded polystyrene (EPS), extruded polystyrene (XPS), rockwool (RW), glasswool (GW), polyurethane (PUR), and wheat straw (WS) insulation materials, whose thermal conductivity behavior was examined within the scope of the study, exhibited similar performance in all cities. The fact that the exterior wall components were designed to fulfill the maximum U-value requirement according to the TS 825 standard is an essential factor in this situation. According to the data obtained in the study, insulation applications in different climatic zones and on all facades significantly contributed to indoor comfort by increasing the interior surface temperatures in the winter months and limiting the temperature fluctuations in the summer months. The fact that wheat straw (WS) insulation material exhibited similar thermal performance to other insulation materials showed that wheat straw (WS) could be a good alternative to conventional insulation materials when used in appropriate thicknesses. As a result, since wheat straw (WS) is a natural material, it causes much less energy consumption and carbon emission in the production process, as opposed to conventional insulation materials, and this has emerged as the most crucial advantage of this material. However, wheat straw (WS) insulation material requires a greater thickness than other materials to exhibit good thermal performance, which can be considered a disadvantage since the material will increase the building load. Future studies, which consider the effect of various insulation thicknesses on thermal transmittance behavior and external wall surfaces' heat gain and loss energies, will help fully define the potential of using wheat straw (WS) insulation on buildings' external walls.

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Parametric modelling and geometrical arrangement of ellipse-plan diagrid structural system

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Abstract. The diagrid structural system, developed for high-rise buildings, is widely used in such structures due to its structural efficiency and architectural potential. The structural system offers a unique application area in terms of angular arrangement and geometrical harmony of the elements in plans with nonlinear forms. This study aims to standardize the bearing elements of the diagrid carrier system with an ellipse-plan, which is nonlinear and exhibits variable curvature, into a homogeneous arrangement. The geometric arrangement of a 60-storey diagrid structure with a floor height of 4 meters was modelled using Grasshopper. The result was a non-extruded shape characterized by variable cross-sections. Additionally, geometric arrangements were easily modified using parametric tools during modelling. In addition to the model, the ellipse-plans were divided into equal lengths using the implemented code. These divisions were then used to determine the coordinates of the node points. The calculation of the coordinates of the node points was an important stage in the arrangement of the structural elements of the system. In the modelled study, different node angles and diagonal element lengths were obtained by varying the number of diagrid modulus plies and the number of node points. This study provides a potential approach for the geometric arrangement of ellipse-plan diagrid systems and the standardization of their structural elements.

Keywords: Diagrid structural system; High-rise buildings; Geometric arrangement; Parametric modelling; Ellipse-plan

1. Introduction

With increasing urbanisation and population density globally, tall buildings are becoming increasingly important. These buildings not only provided accommodation and workspaces, but also became an indicator of architectural expression and technological developments. For this reason, the design processes of tall buildings are becoming increasingly complex and require the integrated work of different disciplines. Especially in tall buildings, the structural arrangement of structural systems is critical in terms of architectural flexibility and ease of application. In this context, diagrid structural systems are an innovative and flexible structural arrangement method developed as an alternative to traditional column-beam systems (Jani & Patel, 2013).

Diagrid structural systems are geometrically based on the diagrid module, which is the basic building block of the triangular pattern stacked along the height of the building and covering one or more floors. The division of the building into diagrid modules is usefully used for preliminary design and analysis (Mele et al., 2019). Diagrid modules consist of inclined elements and horizontal rings. The inclined elements have a dual function, acting as support and inclined columns (Boake, 2016). In addition, as shown in Fig. 1, the inclined elements are called 'diagonal', while the horizontal rings are called 'ring beam' and are connected at the floor levels with the node.

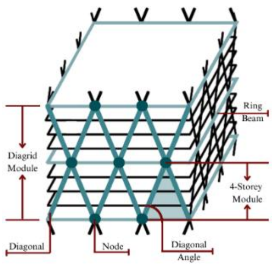

Fig. 1. Eight-storey diagrid structural system module, modified from K.S. Moon (Moon, 2016).

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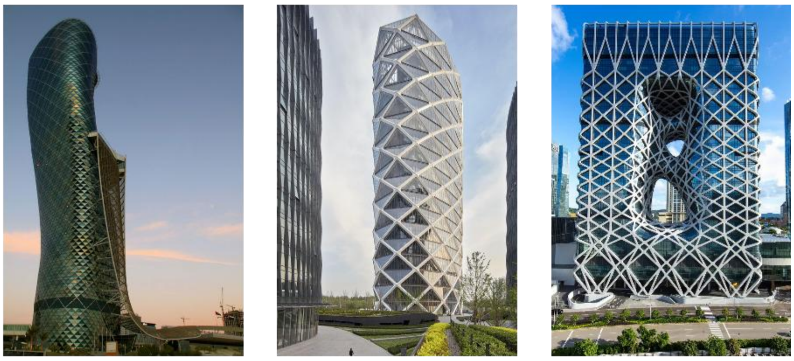
The structure is divided into a series of diagrid modules along its height. In practice, diagrid modules usually cover more than one storey; in Fig. 1, the node point occurs every four storeys. The location of nodes is widely used to identify diagrid modules (Asadi & Adeli, 2017). The positioning of diagrid modules and the placement of nodes directly impact the overall mechanical behaviour and stability of the structure. This modular structure offers structural efficiency, homogenisation of load distribution and optimised performance in material utilization (Rahimian, 2016). In addition, this structural system provides a flexible design approach that allows the creation of complex geometric forms.

Due to its advantages, the diagrid structural system has been the subject of scientific research for many years. Studies generally address structural optimisation, wind and seismic behaviour, digital design and fabrication methods, and integration of architectural expression (Moon, 2016; Mirniazmandan et al., 2018; Tomei et al., 2018; Brunda & Bhavanishankar, 2022; Naik & Modhera, 2023). In addition, research on the plan geometry and nodal angle of structures has enabled the development of various properties in these areas. However, studies in the literature have generally focused on structures with idealised simple geometries (such as square, circle and triangle plans) and research on complex geometries such as ellipses has been limited. The main reason for this situation is that plans with simple geometries provide an important convenience in structural analyses. This makes it possible to focus on a single geometrical parameter (e.g. height or diagonal angle) while balancing stiffness and mass distribution (Moon, 2016). The study of a complex geometry such as an ellipse may require several parameters to be varied simultaneously (eccentricity, radius of curvature, load distribution, etc.), which makes comparative research difficult.

Square/rectangular plans have been frequently used in research as it is possible to ensure that each floor plan is the same and studies with similar dimensions have been developed. Moon's (2008) study modelled with 36x36m plan sizes of 40, 50, 60, 70 and 80 storeys also proposed the optimum angle value for high-rise buildings. Furthermore, in subsequent studies, researchers adopted the 36×36 m plan type as the basic specification for modelling and analysis. In Moon (2016), 60, 80, and 100-storey diagrid building models were used, and the height of each storey was fixed at 3.9 m. The structural behaviour of different geometric configurations was investigated by showing a 36x36 m square plan and floor plans deviating from the original square form between ±1.5 m and ±4.5 m. As a result of diagrid modules covering eight floors, an optimal diagrid angle of approximately 69° was obtained. In the study conducted by Mirniazmandan et al. (2018), the effects of different plan geometries on a 180-meter-tall building with a diagrid structural system were investigated. In the study, the building plan geometry was considered an important parameter; the plans were formed in circular and polygonal (3, 4, 5, 6, 8, 10, 12-sided) forms. In the models, 10 diagrid modules were used. The diagrid angle (θ) was calculated depending on each module's height and base width; for example, an angle of approximately 63° was obtained for a 6-storey module. In the study, the effects of different diagrid angles such as 33.5°, 53°, 63°, 70° and 81° were investigated. Thus, the effect of different plan geometries on structural performance was evaluated through parametric models. This study by Tomei et al. (2018) used a 90-storey high-rise building model with a total height of 351 metres and plan dimensions of 53×53 m square. The height of each floor was taken as 3.9 m, and this model served as the basis for the evaluation of real-scale diagrid systems. Different plan geometries, diagrid angles and module placements were evaluated. Brunda & Bhavani Shankar (2022), in order to determine the optimum grid geometry of the diagrid structure, models with different numbers of stories and diagrid angles were created, and their performances were analysed. For the same area (1296 m²), square (36 m × 36 m), rectangular (54 m × 24 m) and circular (diameter ≈42.6 m) plan models were created. The modelled structures are 12, 24, 36, 48, 60 and 72 storeys, each with a height of 4 m. It was observed that the optimum diagrid angle was 60° for 12 and 24-storey models and 69° for 48, 60 and 72-storey models. Naik & Modhera (2023) studied a 36-storey high-rise building model with 36 m × 36 m plan dimensions and a height of 3.6 m on each floor. The model's building plan geometry is square, and the diagrid system is arranged as triangular modules repeated around the building. The angle of the diagrid elements along the whole structure was determined as 74.50° (the optimal range recommended in previous studies is generally accepted to be around 65°-75°).

In summary, the literature has largely focused on optimising the diagrid system in prismatic tall buildings with square, rectangular, or circular plans. Nowadays, the use of diagrid carriers is also seen in tall buildings with complex plans and forms, curved, twisted, or free-form high-rise buildings, and the gaps in the literature on this subject are beginning to be filled.

For structures that are not perfectly symmetrical, such as ellipses, and whose plan dimensions vary in one axis relative to the other, the design of diagrid structural systems poses unique challenges. The study on ellipse by Rosin & Pitteway (2001) examined the mathematical foundations of the ellipse and the modelling of the ellipse form by applying segmented arcs. In addition, while the study demonstrated the potential of the ellipse to be applied in structures, it also addressed the computational difficulties that may be encountered in construction applications of this geometry. These mathematical foundations show that ellipse-plan geometry can be integrated into building design. However, the geometrically irregular plan in the diagrid structural system can form façade diagonals with different angles and dimensions in each region. An example is the Capital Gate Tower in Abu Dhabi (Fig. 2a.), which is designed with an 18-degree inclined silhouette.



a)Capital Gate Tower in Abu Dhabi b)Poly International Plaza in Beijing c) Morpheus Hotel in Macau

Fig. 2. a, Capital Gate Tower; b, Poly International Plaza; c, Morpheus Hotel (URL-1, 2, 3).

The plan of the building varies from a curvilinear triangle to a curvilinear quadrilateral, and a diagrid structural system is used both externally and internally. Due to the curvature of this building form and the curvilinearity of its plan, more than 800 unique nodal connections had to be designed (Schofield, 2012). The fact that each node is geometrically different from the other causes profound complexity in terms of manufacturing and assembly. As seen in the analysed studies, rectangular, square plans with a fixed angle (regular) diagrid may be sufficient to produce only a limited number of types of nodes since the façade modules can be repeated. This example clearly shows that the concept of standardised elements becomes difficult in ellipse or free-form plans.

Similarly, the Poly International Plaza (Fig. 2b.) in Beijing has an ellipse-plan. The diagrid structural system is arranged in four-storey modules with a distance of approximately 18 m between each module. The total number of nodes in the structure is more than 200, and the angle of the node is 50°. The architects designed the diagonals much more oblique than usual (below about 40°) to give the building a lantern appearance (Chow et al., 2017).
In tall buildings with ellipse or similar free-form plans, homogenisation of element dimensions and nodes becomes complex and may adversely affect structural performance. In such free forms, classical methods are insufficient to efficiently and feasibly design the diagrid system. Accordingly, parametric modelling-based approaches have been increasingly used in recent years to overcome these challenges.

Advanced parametric design and analysis tools are key in optimising diagrid systems with complex geometries. Parametric design is an approach that dynamically updates the design form by comparing many interrelated models within specific parameters and rules. This allows a systematic examination of the effect of each parameter on other parameters and the main form (Ardekani & Alaghmandan, 2023). In addition to parametric modelling, special scripts and algorithms have been written for complex models to meet the model's needs. In some buildings with diagrid structural systems, models that optimise the positions and angles of diagrid elements have been developed with scripts. For example, in the design of Morpheus Hotel (Fig. 2c.), the Zaha Hadid Architects team created a parametric model of the building form and exoskeleton and wrote special 3D scripts to define the diagrid structural system (Piermarini et al., 2018). This work exemplifies how parametric modelling in the diagrid structural system rationalises the complex form and transforms it into constructionally manageable parts.

In this study, with a similar approach, the geometric arrangements of diagrid structural systems used in high-rise buildings are examined on ellipse-planned building forms in order to homogenise and standardise the elements. Using parametric modelling techniques aims to optimise the angular and dimensional compliance of the structural elements. This approach aims to develop potential solutions for the optimisation of the building system.

2. Methodology And Parametric Modeling

The building was modelled with the Grasshopper plugin on Rhinoceros, using the flexibility offered by digital design tools to plan and implement each stage in detail (Fig. 3.).

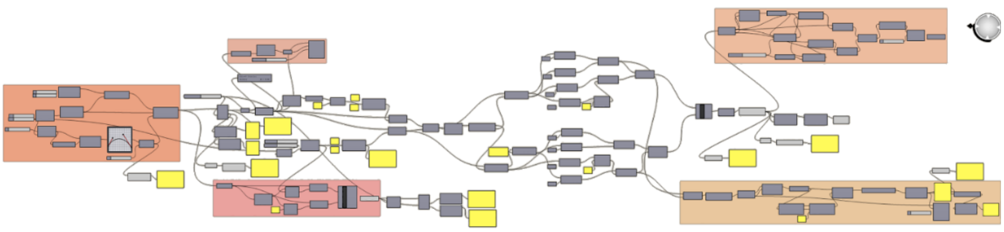


Fig. 3. Interface image of the study modelled with Grasshopper plugins.

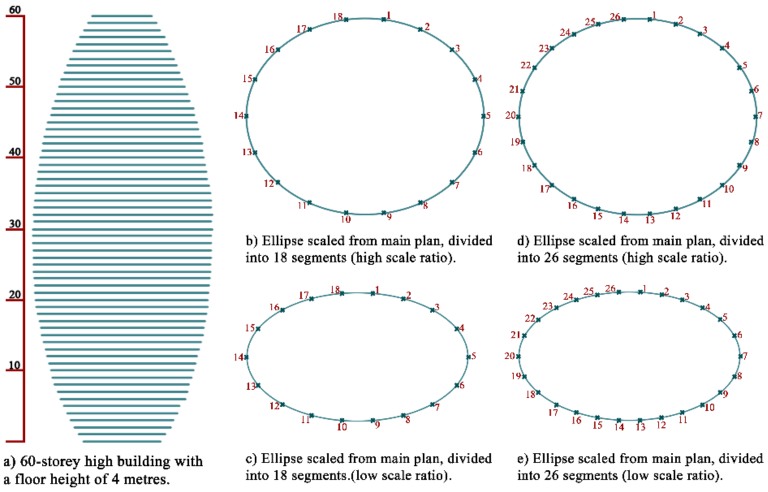


Fig. 4. a, modelled 60-storey high-rise building; b and c, ellipse divided into 18 equal parts; d and e, ellipse divided into 26 equal parts.

In this context, the parametric design method allows the design form to be dynamically updated by comparing a large number of interrelated models within certain parameters and rules. This allowed us to systematically examine the effect of each parameter on other parameters and the main form (Ardekani & Alaghmandan, 2023).

Thanks to this method, all parameters to be included in the model and the relationships between them were determined in detail. In the reviewed studies, parametric models generally adopted reasonable base dimensions, which are common in the existing literature, rather than extreme or unconventional dimensions. The dimensions utilized for square, rectangular, or circular plan forms were observed to be similar across these studies. Although there is currently no existing research specifically focusing on ellipse-plan forms, dimensions and parameters used in this study were derived by referring to analogous tall building designs documented in the literature. The modelling process started with the definition of the general geometry of the targeted tall structure. Considering the design criteria widely referenced in the literature, 40, 60 and 80-storey building studies and typical slender tower type projects were extensively analysed in this context. In the parametric modeling, the height and number of storeys of the structure were chosen to ensure that the structure remains within a certain slenderness range; for example, a 60-storey building with a storey height of 4 meters (Fig. 4a) was considered.In this context, the plan size for the 60-storey diagrid structural system was determined to give a ratio of approximately 1:6 with the building height (36 m base width and ~216-234 m height) (Moon, 2008, 2011, 2016).

The geometric properties of the ellipse-plan were determined, and 38x46 m values were used as dimensions. In addition, the geometric changes of the ellipse-plan at different scales could be analysed in line with the determined scale range (0.5-1.5) (Fig. 4b.,4c.,4d.,4e.), thus preserving the building's geometric integrity and aesthetic harmony.

After modelling the ellipse tall building, more specific methods were applied to calculate the locations of the points that will divide the ellipse into equal parts. In calculating the locations of the points, considering the changes in the dimensioning of the ellipse, the division of ellipse-plans into equal lengths is based on geometric calculations. For idealized simple geometries, the division can be done quickly by taking the center angles equal to the axes and other directions, but this method is insufficient for the ellipse (Rosin & Pitteway, 2001).For this reason, a special Python script was developed to divide each ellipse-plan into equal segments of equal length, which is implemented in Grasshopper (Fig. 5.).

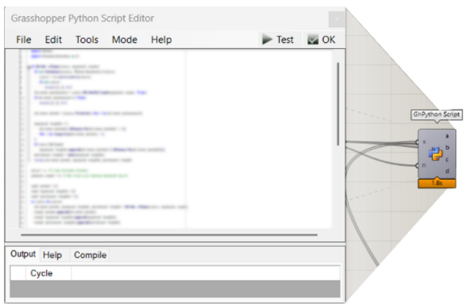


Fig. 5. Python script for the model implemented in Grasshopper

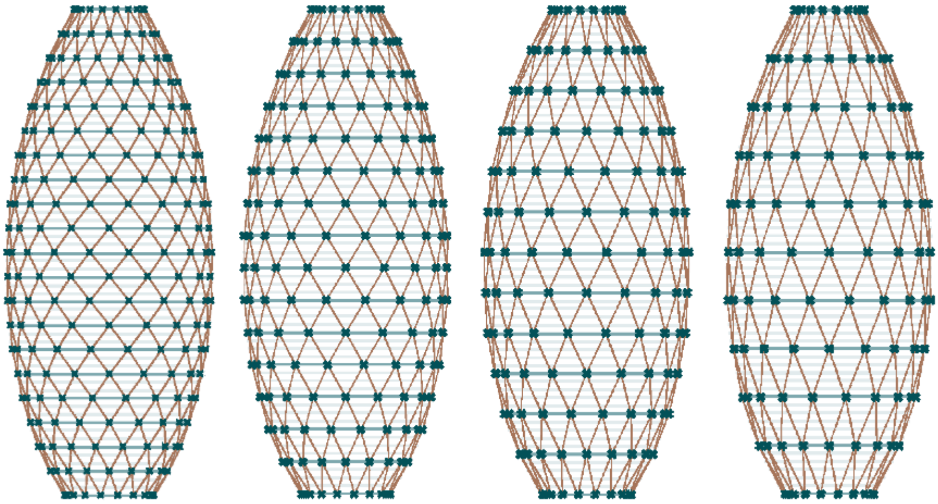


Fig. 6. a, module of 6-storeys; b, module of 8-storeys; c, module of 10-storeys; d, module of 12-storeys

The script developed in this study uses Rhino and RhinoScriptSyntax libraries and takes each ellipse curve in the model as input. First, the script takes essential inputs from the model, such as ellipse dimensions and the number of nodes, and calculates the splitting parameters according to the number of segments specified on the given curve (for example, n segments). While the code parametrically divides the ellipse-plan, it also allows the user to choose the number of nodes in different values such as 18, 20, 24, 26 or even 30 (Fig. 4b.,4c.,4d.,4e.). Equally spaced division points are obtained on the curve. The segment lengths are determined by calculating the distances between two consecutive points; if the curve is closed, the distance between the last and first points is added. As a result, the script calculates each ellipse's segment length, the ellipses' total circumference, and the coordinates of the points obtained. The coordinates of the points obtained as a result of this calculation are used as a reference in determining the coordinates of the nodes and optimising the structural element lengths.

The building height is first divided into triangular modules in modelling the diagrid structural system. In the model, the triangular modules are framed by the diagonal elements of the floor edge beams, and these triangulations come together to form a diamond-like structure (Moon et al., 2007). The ply numbers of the diamond-shaped diagrid modules cover 6,8,10, and 12 plies to divide 60 plies equally (Fig. 6.).

According to the number of diagrid module floors and the number of nodes in a floor, the values of the diagrid structural system elements and connections change. Geometric relationships can be established with these geometric parameters of the structural system. The total number of diagonals (T_{dia}) and the total number of nodes (T_{nod}) can be calculated using the number of storeys diagrid module (N_{module}), the number of nodes in a storey (N_{nod}), and the total number of storeys of the structure (N_{str}). In the equation for T_dia, the number of elements in two directions in each module and the nodes at the base level are considered. The equation is defined as follows:

$$T_{dia} = \frac{4N_{str}N_{nod}}{N_{module}} \tag{1}$$

The constant term 4 arises from doubling the floor ratio and the number of nodes. For example; when the total number of storeys of the structure (N_{str}) is 60, the number of nodes in a storey (N_{nod}) is 22, the number of storeys diagrid module (N_{module}) is 8, the total number of diagonals (T_{dia}) is 660. Similarly, the equation for the total number of nodes is defined as follows:

$$T_{nod} = N_{nod}\left(\frac{2N_{str}}{N_{module}} + 1\right) \tag{2}$$

In the equation, the term $2N_{str}/N_{module}$ represents the number of triangles along the structure's height; constant 1 is then added to account for the nodes in the topmost triangle. For example, when the total number of storeys of the structure (N_{str}) is 60, the number of nodes in a storey (N_{nod}) is 22, and the number of storeys diagrid module (N_{module}) is 8, the total number of nodes (T_{nod}) is 352. These formula-based calculations can be compared with the outputs of the parametric model. During both calculations and modelling, different variations were quickly generated and values were obtained as one of the advantages of parametric design. In this context, systematic variation of the parameters specified in the model (e.g. number of nodes, number of modules) allowed the lengths and angular properties of the elements in the structure to be examined through the geometric outputs obtained. This methodology is presented in detail to guarantee the study's reproducibility; the digital tools and algorithms used are explained in a way that contributes to the study's scientific validity.

3. Results and Discussion

3.1. Model Results

In the parametric modelling study, geometrical arrangements of the ellipse-plan diagrid structural system were made using the code developed. The data obtained with the developed Python script are presented in tabular form (Table 1). At the foundation of this study, the ellipse-plan's perimeter was divided into equal segments. In this way, the obtained nodes were utilized as a reference point for placing the primary structural elements of the diagrid system. Table 1 presents the numerical variations in the dimensions of the diagrid structural system, resulting from dividing the ellipse into equal segments, depending on the number of nodes and storeys per diagrid module.

The values in this table show the ranges of changes in element dimensions and angles as the number of nodes and storeys per diagrid module increases. For instance, increasing the number of nodes allows the ellipse-plan to be divided into more segments. In addition, changes in the number of diagrid module multiples effectively determine diagonal element lengths and angular arrangements.

The data in the table provides important information about specific parameters (e.g. minimum/maximum ellipse segment length, average diagonal length, node angles) of the ellipse-planned diagrid structural system. Firstly, the minimum and maximum ellipse segment lengths vary according to the number of nodes per floor, and the segment lengths decrease as the number of nodes increases. For example, when 20 nodes were used per floor, the minimum ellipse segment length was 3.019 metres, and the maximum segment length was 8.836 metres, whereas, with 24 nodes used per floor, the minimum ellipse segment length was 2.516 metres and the maximum segment length was 7.365 metres.

The number of storeys per diagrid module is a critical parameter affecting the overall consistency of the geometry. As the number of storeys of the diagrid module increases (6, 8, 10 or 12 modules), a decrease in the number of diagonals, an increase in the average diagonal length, a decrease in the number of nodes and an increase in the average node angle was observed. While this increases the length of the elements, it also allows the distribution of the nodes throughout the structure to settle in a specific order.

Table 1. Length and angular variations of diagrid elements based on the number of nodes and diagrid module layers

Number of Points Per Floor	Minimum Ellipse Segment Length	Maximum Ellipse Segment Length	Number of Storeys Per Diagrid Module	Number of Diagonals	Average Diagonal Length	Number of Nodes	Average Node Angle
18	3.354 m	9.816 m	6	720	15.062 m	378	53
			8	540	18.756 m	288	58
			10	432	22.628 m	234	62
			12	360	26.600 m	198	64
20	3.019 m	8.836 m	6	800	14.643 m	420	55
			8	600	18.420 m	320	60
			10	480	22.350 m	260	63
			12	400	26.365 m	220	65
22	2.745 m	8.033 m	6	880	14.324 m	462	57
			8	660	18.166 m	352	61
			10	528	22.142 m	286	64
			12	440	26.189 m	242	66
24	2.516 m	7.365 m	6	960	14.076 m	504	58
			8	720	17.971 m	384	63
			10	576	21.982 m	312	65
			12	480	26.055 m	264	67
26	2.323 m	6.798 m	6	1040	13.879 m	546	59
			8	780	17.816 m	416	64
			10	624	21.856 m	338	66
			12	520	25.959 m	286	68

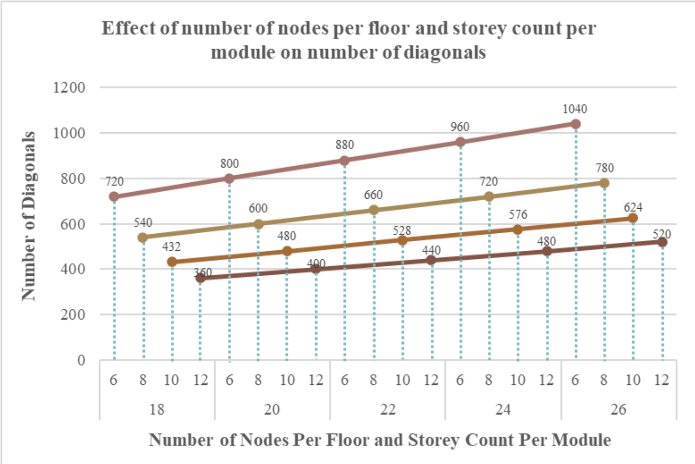


Fig. 6. Effect of number of nodes per floor and storey count per module on number of diagonals

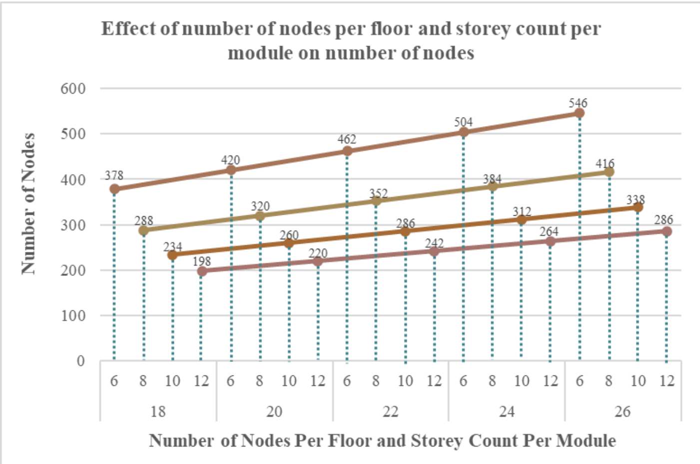


Fig. 7. Effect of number of nodes per floor and storey count per module on number of nodes

As seen in fig. 6., when the number of nodes 18, and the number of diagrid module multiples is increased from 6 to 12, the number of diagonals decreases from 720 to 360, and the diagonal length increases from 15.062 metres to 26.600 metres. This overlaps with the increase in the length of the diagonal elements when the horizontal and vertical support network of the diagrid structural system becomes more sparse.

The total number of nodes also varies according to the effect of these parameters. As the number of points used to divide the ellipse-plan perimeter into equal segments increases, the lengths of the diagonal elements shorten, and the angles between the nodes decrease. In addition, the increase or decrease in the number of nodes and the preference for more or less modulus coefficients affect the density of the carrier system to be formed along the façade. Using more nodes and less modulus coefficients (e.g., an 8-storey module) reduces the distance between the elements by creating a denser network structure in the outer frame of the building. Fig. 7. shows 420 nodes for a 6-storey module with 20 nodes, while this number increases to 546 for a 6-storey module with 26 nodes. This approach requires a balance between structural efficiency and ease of fabrication and assembly since increasing the number of nodes increases the number and complexity of joint details.

The average node angles vary between 53° and 64°, reflecting the general trend of the angle of the diagonal elements to the vertical, as seen from the data taken from the model. As the number of nodes and the number of diagrid module storeys increases, the node angle increases and the elements are placed with a steeper geometry along different storeys. Increasing the diagrid element angle in tall buildings is frequently discussed in the literature, especially in improving flexural stiffness (Moon, 2014). However, it should also be considered that angular increase may require different joint details during the manufacturing and assembly process.

In summary, the data in Table 1 show that the diagrid structural system with the ellipse-plan significantly affects the parametric variables (number of nodes and diagrid modulus multiples). These observations constitute an important data set for the geometric optimisation of the structural system or structural performance evaluation in the later stages of the study and provide quantitative data to guide design decisions.

3.2. Structural and Architectural Evaluation

Although important parameters such as structural material, bearing capacity or load distribution of the load-bearing system modelled in this study were not addressed, the study's results allow various inferences regarding structural efficiency. The model results show that parametric variations affecting the element dimensions and node angles provide important data to establish a consistent approach to geometrical arrangement. In this context, it is seen that the data obtained with different node numbers and diagrid modulus coefficients have significant effects on other elements of the structural system. If it is inferred from the data in the table, increasing the node density caused the diagonal elements to have a more homogeneous distribution. This homogeneity resulting from increased nodes may provide a more regular geometric structure throughout the structure and encourage equal distribution of loads on the elements. In addition, since the average length and node angles of the diagonal elements can play a determining role in the possible flexural stiffness and horizontal load transfer of the system, it will be possible to perform a more comprehensive performance analysis by including factors such as material properties and load combinations in future studies.

However, dividing the ellipse-plan into equal parts with the script developed in the study contributes to homogeneity by helping to standardise variations in the geometric arrangement of the diagrid system. Standardisation of element dimensions within certain limits offers significant advantages in adapting building elements to prefabricated production processes. Therefore, this study provides a valuable perspective for adapting a parametric design approach to prefabricated production processes.

When evaluating architectural harmony, the ellipse-plan form is evaluated using a parametric approach, which supports innovative applications in the design processes of modern architecture. The ellipse-plan provides a much more dynamic appearance than square or rectangular plans and allows diagonal lines to add functional and aesthetic value to the building.

4. Conclusions

Within the scope of this study, geometrical arrangements of the ellipse diagrid structural system have been investigated with a parametric modelling approach, and findings for the standardisation of the structural elements have been obtained. Ellipse-plans with different width scales are divided into equal segments using the developed code script, and diagonal element lengths, segment lengths of ellipses and angles of the node are calculated parametrically. The effects of the parametric changes made in the model on the element dimensions are numerically analysed. The results showed that changing the number of nodes resulted in differences in ellipse segment lengths, and changing the number of nodes and diagrid modulus coefficients resulted in differences in the lengths and angles of diagonal elements. In this context, the main output of the study is the demonstration that standard dimensioning can be approached under certain conditions with parametric control in ellipse-planned diagrid carrier systems. The ability to control the diagrid structural elements within a specific standard can make the load distribution, connection details and overall system behaviour more predictable. This, in turn, may lead to favourable project costs and implementation time results by enabling prefabricated applications during the production and construction phases.

The present study, modelling and parametric analyses provide an approach to the parametric regulation of the diagrid structural system in non-linear, variable curvature plans and non-standard geometries. The structural material of the structural system modelled in this study is not specified, and no bearing capacity or load distribution analyses are performed. In future studies, the structural strength of the ellipse diagrid structural system should be comprehensively evaluated by integrating the existing model with the material performance and dynamic load analyses. In addition, detailed simulation studies should be carried out to optimise the system by considering different load scenarios, environmental factors, and effects on long-term usage.

In conclusion, this study presents an approach to the geometrical arrangement and standardisation of the structural elements of the ellipse diagrid structural system while demonstrating the potential advantages of the system both structurally and architecturally. The obtained parametric data provides a solid basis for future detailed structural analyses and gives important clues for the optimisation of the system and its application potential. Future comprehensive studies will increase the applicability of this model and lead to sustainable and economical building solutions by integrating it with modern construction technologies.

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Evaluating generative AI capabilities for architectural visualization

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Abstract. Architecture is one profession that involves a lot of development and change, architects are involved in the planning of creative and provocative works. The process involves the deployment of the different means of visualization and or techniques. Within the past twenty years, the most utilized means of visualisations have included AutoCADs, Revit, SketchUp, Rhinos for 3D modelling and V-Ray; Lumion or Corona rendering. However, the last three years brought a revolution in the architectural visualisation, advancing AI. This paper's goal is to offer a brief assessment of the application of various generative AI technology in architecture. Moreover, it tries to use similar procedures to these tools when they are used in similar conditions. After that, the productivity of such tools is measured in the sense of their ability to create realistic and innovative architectural designs. This paper's results and discussion focus on the use of AI in the design aspect of architecture and outline the advantages of adopting AI-based generation in architectural models as well as the general challenges and opportunities of designing generative AI in architectures.

Keywords: Architectural rendering; Comparative analysis of AI tools; Generative AI

1. Introduction

Over the past few years, generative AI has become an essential component of architecture since it reduces the amount of human contribution in the process. When it comes to the content generation, generative AI has been successfully applied for such tasks as text-to-image synthesis, as well as the text-to-3D model creation, getting very close to or achieving state-of-the-art performance (S, 2023). AI image generators are reinventing an architectural landscape through greater design creativity and efficiency. With issues such as prompt proficiency and ethical considerations still unresolved, these tools are nonetheless capable of changing architectural design and education. Future advancements in artificial intelligence development will take integration of these tools into the architectural workflow one step further, allowing a rise in inventive and collaborative approaches (Beyan & Rossy, n.d.).

This sector is multifaceted and is broad in terms of topics, themes, and scope of work because architectural design is extensive (Eilouti, 2021). For each project, there is a need to have a style, and as we proceed to develop complicated designs, there is even more variety. The investigations conducted in the past have shown that architectural preliminary 3D form design is within this domain, in addition to areas such as detailed and optimization design. These are layout designs of buildings considering the nature of generative problem solving (C. Li et al., 2024). A bibliometric analysis of the recent articles containing the keywords identified in the present article showed a significant growth in the number of articles and papers discussing architectural design with the help of generative artificial intelligence. The number of research articles utilising generative AI technology at various stages of architectural design provides insight into the evolution of trends within each subfield. While the majority of research is concentrated on the field of architectural plan design, research in the field of concept design and architectural image production has increased exponentially over the past two years (Eilouti, 2021). This continued growth trend clearly demonstrates that generative AI in architectural design is expanding at an unprecedented rate. It also reflects the architectural design and computer science community's high level of interest and increasing investment in generative AI technologies. Table 2 presents the most commonly employed productive AI techniques. In contrast to the most prevalent diffusion models (such as Dall-E 2, Midjourney and Stable Diffusion) and their derivatives, artificial intelligence tools have been selected for this article (C. Li et al., 2024).These tools can be employed at various stages, from student to professional levels.

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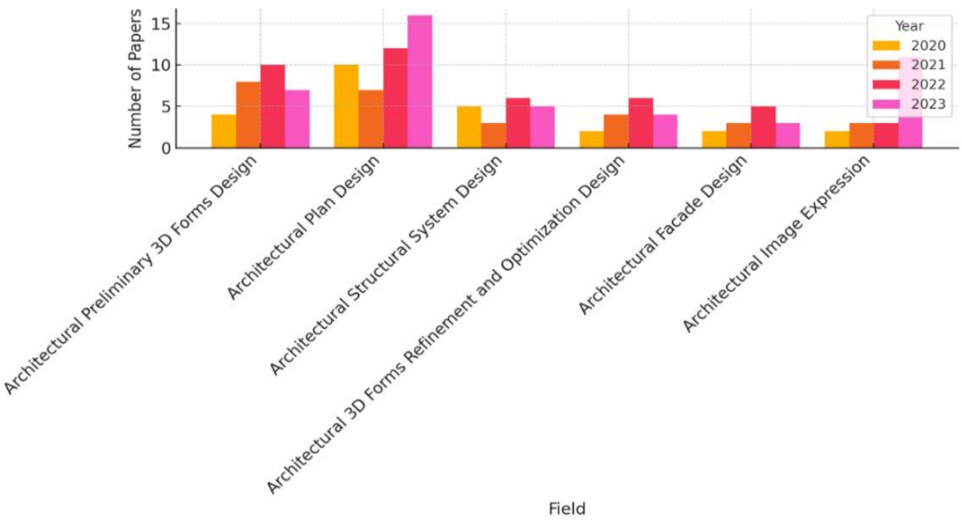

Fig. 1. The number of research papers using generative AI technology to various architectural design steps (Kapliński & Bonenberg, 2020)

In this regard, the latest studies in the literature were examined and the following results were obtained. (P. Li et al., 2024) test that comprehensive workflow on the architectural design which is sketch to real model. It decided that defining architectural style, material, type, and landscape is crucial for directing the AI tools. Also, the paper presents the creative, rapid, and effective design methods for AI from the early stages to the final model. (C. Li et al., 2024) this study examines how designers employ image AI to inform their 3D designs, as well as the limitations of this approach. The findings indicate that image AI can be a valuable resource for architectural designers. (C. Li et al., 2024) search for the using generative AI technologies during the architectural design phase. 3D generative and diffusion models present different creative tools and integrate architectural design. This paper highlights generative AI tool productions like 3D models and 2D images and videos. In conclusion, AI is adopted in the architecture sector, increasing its use and applications while forcing off conventional boundaries. This paper also suggested that while revealing potential of the AI, new research ways and application areas for architectural design. (Yıldırım & Demirarslan, 2020) discuss that evaluations have been made on where artificial intelligence is in the design process today and how useful it is to the interior designer. Conclusions; AI benefits the analysis and synthesis phase of the design.

2. Method

Nowadays, Generative AI tools are increasing and users meaning architects and architectıre students are trying lots of programs for developing designs (Zhang et al., 2023). This is important for them because the last stage is presenting someone and the opposite side should apprehend the project. The AI tools are easy for them however all of them don't give similar results under the same conditions. To determine this problem, the most popular five generative AI rendering (Prome AI, Versa, Visoid, Mnml AI, Lookx AI) programs are used and enter the same solid project photos and the same prompts. The project defines a rectangular building and hotel concept. The most popular architectural prompts are examined and this prompt text is created according to this.

2.1. PROMEAI

The PromeAI represents a major advancement in generative AI, providing a suite of tools to enhance creative workflows. Its sketch-to-render functionality transforms simple sketches into detailed renders, while the Erase & Replace feature allows seamless modifications of specific image elements. Embedded capacity for HD up scaling is useful in the platform as imparts a higher resolution before it is scaled up to high definition standards. Moreover, it may also be the case that users may have an image of what they would like to be produced and this in a way would assist in setting the measures as per what should be produced in as much as visual measures are concerned. Furthermore, the unique aspect of PromeAI is that users can turn the 'creativity knob', which means that they can influence how much interpretation the changes made by the AI. Due to these characteristics, PromeAI becomes a valuable and innovative approach when it comes to art and design performed in the digital space.

2.2. VERAS

VERAS system is offered by Evolabs and is targeted at those people who willing to achieve the dramatic look. In this regard, the system offers a number of set programs that may be used to this end. The templates can also be enhanced with prompts and accurate project match as to what is needed for the specific task and that is very vital especially where the design is geometrically constricted and a high precision is called for. The basic features of this software are the Geometry Slider since it set the geometry override of the scene, and the Render Selection if the user only wishes to fine touch to some area on the project. The "Build from the Same Seed" option can be resumed of reflecting the patterns of repeated thoughts as people are let to go back to the previous blends and further elaborate them. Also, one of the functionalities of the web application is to possess the image manipulation functionality that allows new images to be created from the others. All these aspects allow VERAS to act as a special and efficient tool of digital designing and affect the enhancement of professional performance.

2.3. VISOID

VISOID can be defined as specialized architectural rendering tool that employs artificial intelligence technology to fast deliver high quality 3D images. The fact that it is cloud-based also leads to a large number of various specialists being able to access it with no need for specialized hardware to render quickly. In this case, it is easy to use VISOID to visualise because the process is simplified by the fact that multiple and complicated works such as scene generation, lighting and collection of objects are all done by the AI tool. This cuts out the time needed for testing as the program increases design productivity which enables architects to work more on the style of their projects. It means that architects are provided a chance to engage in a kind of a game where one can influence moods, environments, colours or even switch between styles within a relatively short time span. However, with regards to the given project one has to provide very detailed prompts, rendering is very time consuming, the tool saves the work as well as suggests enhancements to the images which substantiates that this tool is very versatile and of fairly good quality.

2.4. MNMI.AI

MNML AI is revolutionizing architectural design as an AI-powered assistant that transforms ideas and sketches into impressive designs with just a few clicks. This platform enhances creativity and efficiency in the design process, catering not only to architects but to anyone seeking faster, more efficient design solutions. MNML AI's user-friendly interface enables designers to swiftly advance their projects, turning sketches into professional designs and pushing creative boundaries. Its features herald a new era in architecture and digital design, empowering users to expand project scope, emphasize originality, and overcome design challenges. MNML AI significantly streamlines the design process, making it more accessible and effective.

2.5 LOOK X AI

LookXAI is an advanced AI tool designed for early concept iterations in architecture. This highly customizable and trainable model allows architects to upload reference images or samples to generate initial design ideas. Key features include the Style Adapter and Word Template, which enhance the quality, depth, architectural precision, and style of renderings. The rescaling feature corrects imperfections and improves image quality, facilitating subtle optimization of projects. LookXAI supports faster and more effective design progress, enabling architects to realize their original projects more easily. Additionally, it offers video rendering capabilities. Available at a low cost, LookXAI provides substantial support in the early design stages, boosting architectural creativity and efficiency.

In order to write a prompt, it is essential to utilize a correct prompt method and an equation can be created for this purpose (Liu et al., 2023). If one considers the process as an order, it is only when the correct information is provided that the desired result can be achieved.

Building type+Architectural style+ Architect name+ Material+ Rendering style+ Imagination Landscape or surroundings + Light + Developer words

Prompt Text (Table 1); *"Hotel project, contemporary style, design by Zaha Hadid, white concrete building, organic facade form, sustainable material, Vray render, aerial perspective view, ambience lighting, greenery, super realistic, high detail, high resolution, night time render*

Negative prompts; *low quality, deformed, blurry "*

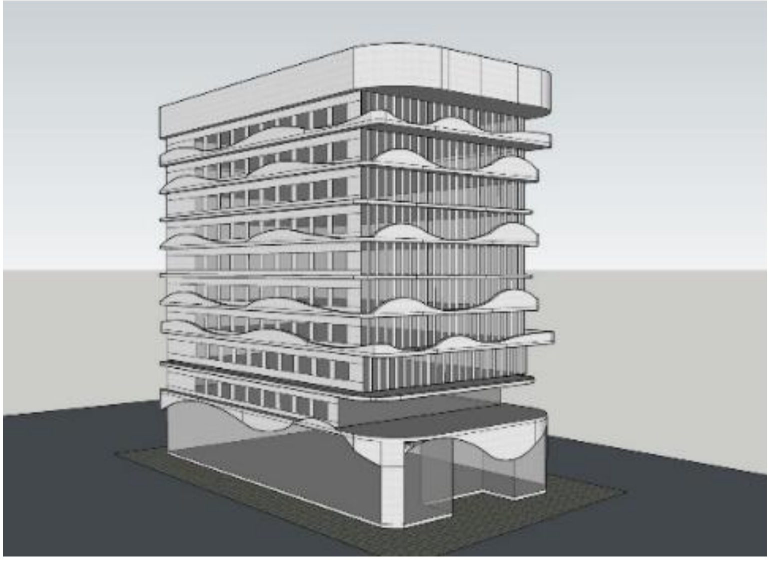

Fig. 2. Solid model of the building (Created by Author)

The image depicts a 3D architectural model of a multi-story building designed in SketchUp. The building has a modern, sleek appearance, with nine floors. The design incorporates undulating, wave-like patterns on the facade, giving it a distinctive and dynamic look. The ground floor features a glass entrance, which appears to be part of a commercial or public space. The structure follows principles of modern and sustainable architecture, emphasizing both aesthetic appeal and functionality. The building's overall form is rectangular, with each floor extending slightly outward, creating a sense of depth and movement in the design. It is situated in an urban environment, as suggested by the simple, gray context of the surrounding area in the model.

Table 1. Prompt List (Archi Lab, 2023)

MATERIAL	STYLE	FACADE	BUILDING	LANDSCAPE
Aluminum	Ancient Egyptian	Art Deco Facade	Architectural	Alpine Landscape
Framing	Ancient Greek	Bamboo Facade	Landmarks	Arid Desert
Asphalt	Art Deco	Brickwork	Cityscape Features	Landscape
Bamboo	Art Nouveau	Facades	Commercial Towers	Autumn Forest
Brick	Arts and Crafts	Cladding	Futuristic Towers	Bamboo Grove
Cement Board	Baroque	Corrugated Metal	Glass Facades	Beachfront
Concrete	Bauhaus	Curtain Wall	High-Density	Best Quality
Drywall	Beaux-Arts	Facade	Development	Cinematic Quality
Fiberglass	Brutalist	Decorative	High-Rise	Coastal Cliffs
Foam Board	Byzantine	Facades	Apartments	Corona Render
Glass	Chinese Traditional	Digital Printed	High-Rise	Countryside
Granite	Classical	Digital Screen	Construction	Meadow
Limestone	Constructivist	Facades	High-Rise Designs	Dense Jungle
Marble	Contemporary	Dynamic Facade	Iconic	Dry Savannah
Masonry	Critical Regionalism	Geometric	Skyscrapers	Frozen Tundra
Metal Roofing	Cubist Architecture	Facades	Megatall Buildings	Grassland Plains
Plaster	Deconstructivism	Glass Curtain	Modern Skyscrapers	High Detail
Plastic	Expressionist	Walls	Residential	High Resolution
Plywood	Architecture	Green Facade	Skyscrapers	High Resolution
Quartz	Futuristic	High-Tech	Sky-High Structures	Hyper Quality
Reinforced	Gothic	Facade	Skyscrapers	Japanese Zen
Concrete	High-Tech	Hybrid Facade	Steel And Concrete	Garden
Sandstone	Architecture	Industrial Facade	Towers	Lumion Render
Shingles	Industrial			Lush Rainforest
	Islamic			Mangrove Forest

Table 1. (continued) Prompt List (Archi Lab, 2023)

MATERIAL	STYLE	FACADE	BUILDING	LANDSCAPE
Tiles, Metal Roofing	Japanese	Interactive	Tall Buildings	Mountain Range
Steel	Traditional	Facade Metal	Tall Towers	Rocky Canyon
Steel Framing	Minimalist	Paneling	Towering Structures	Rolling Hills
Stone	Architecture	Minimalist	Urban Architecture	Serene Lake
Stucco	Modern	Facade	Urban Growth	Snow-Capped
Tiles	Neoclassical	Parametric	Urban Skyscrapers	Peaks
Timber	Neo-Futurism	Facades	Vertical Construction	Tropical Island
Timber Wood	Organic	Postmodern	Vertical Living	Visual Masterpiece
Wood	Architecture	Facade		Volcanic Landscape
	Ottoman	Reflective		Waterfall Scene
	Parametricism	Facade		Wetland Marsh
	Postmodern	Shuttered		Winter Wonderland
	Renaissance	Concrete		
	Rococo	Solar Facade		
	Romanesque	Terracotta		
	Scandinavian	Facades		
	Structural	Timber Clad		
	Expressionism	Translucent		
	Sustainable	Facade		
	Vernacular	Ventilated		
		Facades		

3. Results

Firstly, floor plans and architectural 3D mass models were created based on the sketches. Subsequently, the mass models were employed to ensure that the architectural renderings were rendered in equal conditions. This process enabled the production of architectural renderings during the concept phase. Table 2 illustrates the overall results produced. Architectural design elements were supported by textual descriptions.

Table 2. The generation of architectural designs from simple sketches has been further develope

AI	RENDER 1	RENDER 2	RENDER 3	EVALUATION
PROMEAI				Details and general perspective are medium level, new generations will be good according to these.
VERAS				General perspective is good level however details are not satisfactory

Table 2. (continued) The generation of architectural designs from simple sketches has been further develope

AI	RENDER 1	RENDER 2	RENDER 3	EVALUATION
MNML.AI				Added more details and generated many different versions.
LOOKxAI				Too much solid and nondetailed render, however, render quality is satisfactory

4. Discussion

The use of generative AI in architectural rendering has proven both promising and exceedingly complex to implement. The contrast at the stage of comparison between different AI tools— PromeAI, VERAS, VISOID, MNML AI and LookXAI indicates distinctive strengths and limitations for each platform. Some provide a large leap in detail and an iterative flow such as PromeAI & MNML AI, while others like VISOID or LookXAI show deficiencies for various reason on the quality of their outputs but with Fractalina producing better results later it could be due to early-stage development problems. Additionally, PromeAI has utilized its sketch-to-render utility and the capacity for HD upscaling to produce detailed images from basic sketches — an impressive display of AI improving creative workflows. On the other hand, VISOID's cloud complex system is better than nothing but easily gets stuck in repetitive and evolutionary paths that are not so realistic as desired: this demonstrates a clear boundary of how much detailed we can afford with prompts before its final output conveys zero realism; which goes to show up-to-date AI capabilities only get you yet this far.

Unique features such as the Geometry Slider and Render Selection tool allow for geometrically precise designs, making this a creative alternative to VERAS Font Family. But even then, it falls short on any level of detail anyway- which only indicates that while generative AI can replicate general viewpoints quite well without difficulty at all from a technical standpoint, reproducing finer details is still more difficult. MNML AI specializes in texture-aware editing fashion design creation, and LookXAI is able to augment simple line sketches with rich detail for high-resolution images. While these tools extend the creative frontier and accelerate design process, LookXAI-generated renders are on the more static side with not enough intricate detailing which showcase a wide scope for enhancements.

The results indicate that, even though generative AI tool technology provides as considerable aid in the early design stages and supports creativity to a greater extent than efficiency improvements yet remain shortcomings which need further research and development attention. This imaging is flawless, certainly very impressive for AI artists, but needs a lot of protein to fully enter the professional practice It must be topped with literature in architect-scale accuracy and detail. In the end, this adoption of generative AI in architecture is breaking traditional limits and allows architects to redefine how designs can be approached. Moving forward, no doubt these technologies will advance further and become vital tools for architectural visualization which create a large margin of room to bring out creativity and innovation in the field. Toward that end, research must be directed at streamlining and extending the capabilities of these tools throughout all stages in architectural design from conceptual development to detailed renderings.

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Reconsidering online whiteboards as collaborative design interfaces in architectural education

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Abstract. Architectural education requires students to develop skills concerning collaboration, communication, and design representation. Novice architecture students often face challenges in teamwork within design studios, traditionally structured around physical interaction, feedback, and iteration. However, the shift toward distance learning, accelerated by the pandemic, has introduced new opportunities for novel pedagogies in design education. Online tools have increasingly supported creativity, problem-solving, and peer learning. Among these, online whiteboards, though not originally designed for architectural design processes, provide an effective medium for idea generation and communication.

This study examines the role of online whiteboards in fostering collaborative learning in architectural education and discusses how more efficient interfaces can be developed. While online collaborative tools have been rapidly integrated into design education, their effectiveness in addressing students' cognitive, perceptual, and sociological needs remains an area for further exploration. Retrospective studies highlight both the benefits and limitations of these platforms, emphasizing the need for more adaptable and profession-oriented tools.

Platforms such as Miro, Moodle, Microsoft Whiteboard, and Google Jamboard serve as research environments to analyze participants' cognitive processes and communication strategies. Among these, Miro is frequently cited as the most effective digital tool for co-design processes. This research investigates its use in collaborative design, aiming to identify specialized interface requirements for architectural education. While emphasizing the potential that the developing digital tools offer for design collaborations, this paper concludes by highlighting certain limitations involving cognitive engagement, software integration, and deficiencies in workflow and structured communication.

Keywords: Design education; Design collaboration; Online whiteboards; Co-design solutions

1. Introduction

The integration of technology and online platforms has significantly transformed collaborative design practices, enabling more efficient communication and coordination among team members. These digital tools foster innovation by facilitating real-time idea exchange, co-creation, and knowledge sharing. Additionally, online collaboration enhances the diversity and inclusivity of design teams by allowing participation from individuals who may be geographically distant or unable to engage in traditional, in-person settings. However, despite its advantages, online collaboration also presents notable limitations. The absence of face-to-face interaction can hinder the spontaneous and tacit exchanges that are fundamental to design ideation and problem-solving. As Margot Brereton's empirical research highlights, design experts derive substantial benefits from social interaction in physical design environments, where implicit agreements and shared understanding emerge naturally (Brereton et al., 1996). Building upon Schön's (1992) perspective, designers often operate with a tacit knowledge that is difficult to verbalize, making physical presence and direct engagement crucial for collaboration. While digital platforms attempt to bridge this gap, the extent to which they can replicate or compensate for these embodied interactions remains an open question that requires deeper investigation.

The COVID-19 pandemic accelerated the widespread adoption of online collaborative tools out of necessity, fundamentally reshaping traditional design workflows (WHO, 2022). Design practice, which has historically relied on physical proximity, sketching, and iterative dialogue, faced challenges in adapting to remote work settings, requiring novel strategies to reconstruct collaborative processes in virtual environments (Slingerland et al., 2022). In response, researchers have increasingly focused on integrating information and communication technologies (ICT) into design education and professional practice, aiming to develop more flexible, adaptive, and interactive

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systems (Saleh et al., 2022). This study builds upon these discussions by examining how online collaboration tools, particularly cloud-based platforms, mediate architectural design processes. Specifically, it investigates the role of online whiteboards as a central medium for structuring collaborative engagement and distributed cognition among design teams. By analyzing how these tools are instrumentalized in contemporary design education, this research seeks to contribute to the broader discourse on the evolving relationship between digital media and architectural pedagogy.

In the realm of design studies, the studies suggest that designers often face significant challenges that impact their progress and creativity (Erbil & Doğan, 2012; Fila et al., 2012; Hemdan et al., 2023). These struggles can be attributed to a lack of experience, inadequate social engagements, and maybe even insufficient use of design tools. In the situated environments of design, designers should also learn to work together by utilizing multiple media with colleagues and participants from other disciplines (Kan & Gero, 2009; Niedergeses, 2012; Ozbaki et al., 2016). The development of communication and design tools enables a notably more efficient collaborative design process between designers (Chamakiotis et al., 2013; Mahmoud Saleh et al., 2023). Recently, architectural design has been considered as a distributed cognitive system, which encompasses a multitude of representational media, virtual and analog design tools, communication channels, and more (Dorta et al., 2016; Thatcher & Brown, 2010). Therefore, providing an analysis that accounts for the distributed nature of design processes has the potential to develop a better understanding on contemporary practices in both educational and professional settings.

2. Background and Current State of Online Whiteboard Integration

One of the most extensively researched topics in the post-Covid era regarding online multimedia tools has been the role of online whiteboard platforms in supporting design activities. Recent studies in this area have frequently analyzed the usability and limitations of these tools by examining the social interactions of design stakeholders (Li et al., 2021). This process has generally been explored through detailed interviews conducted after collaborative design sessions with design students. There are also studies researching the technological modality strategies adopted by students. Sher and colleagues highlight that students actively manage their learning processes by integrating multiple platforms and devices, emphasizing the critical need to examine their strategies for technology adoption (Sher et al., 2019). The observations indicate the presence of diverse "behavioral patterns" in the utilization of various tools, ranging from handheld devices to PCs and desktops. The study highlights that these differing technological modality strategies have a direct impact on the overall effectiveness of students' learning processes.

As interdisciplinary online design and planning practices become integral to co-design processes, more in-depth investigations are needed to cover the internal dynamics of design teams and their evolving methodologies. Key aspects warranting further exploration include agile learning in virtual meetings, simultaneous creativity, reflexive digital design processes, and the mechanisms of visual discussion that facilitate collaborative ideation (Sclater et al., 2001). Scholars studying digital ecologies in collaborative design contexts have mapped the intersections of various online platforms, identifying innovative web-based tools that enhance co-design quality (Cerna & Müller, 2021).

Recent research on design cognition and collaborative practices increasingly associates creativity and adaptability with the use of online whiteboard tools, emphasizing their role in fostering dynamic and fluid exchanges between participants. These tools enable real-time sketching, idea structuring, and multimodal representation, allowing for a more interactive and flexible co-design environment. While various platforms are employed in architectural and design education, Miro Board has emerged as one of the most widely studied for its multi-user, cloud-based interface (Rojanarata, 2020; Cerna & Müller, 2021; Li et al., 2021). However, despite its growing adoption, there remains a critical gap in understanding how Miro Board and similar digital tools are recognized and utilized as creative collaboration mediums in collaborative design settings. Further research is needed to explore how these tools influence design decision-making, knowledge exchange, and the overall efficacy of virtual co-design in fostering innovative solutions.

The advancement of new technologies has significantly enhanced communication among designers, fostering more efficient and interconnected design processes. However, many digital design and collaboration platforms require a steep learning curve, as they necessitate familiarity with specific system functionalities before users can fully integrate them into their workflows (Sclater et al., 2001). Overcoming communication barriers in online design processes has become a critical focus of research, leading to the introduction and examination of various online collaborative tools (Koutsabasis et al., 2011; Peppler & Solomou, 2011). The effectiveness of collaborative design is shaped by several factors, including task interdependence—how closely team members must coordinate their work—and potency, which refers to the collective belief in the team's ability to achieve successful outcomes (Erbil, 2013, p. 9). Digital environments have increasingly become supportive tools in fostering collaboration among student design teams, allowing for more flexible and interactive design processes.

Given the rapid evolution of technology and shifting outcome expectations in design disciplines, it remains challenging to anticipate how the norms of co-design environments will continue to evolve. Computer-supported collaborative work environments are now fundamental components of contemporary design teams, and online whiteboard tools have emerged as a widely adopted medium within architectural design processes. These tools, which integrate multiple layers of social interaction into virtual design processes, warrant further investigation to assess their potential in fostering creativity, enhancing team agility, and promoting interdisciplinary collaboration in architectural education and practice.

Miro Online Whiteboard has recently emerged as a widely adopted platform in design and construction disciplines, with increasing applications in academic research and design education (Pikas et al., 2022). While numerous platforms, such as Moodle, Microsoft Whiteboard, OneNote, Google Jamboard, AWW, and Belkin Stage Pro, offer online collaborative whiteboard experiences, Miro has been frequently identified by architectural researchers as one of the most effective tools for enhancing co-design processes (Galabo et al., 2020; Cerna and Müller, 2021; Camiz, 2021; Pikas et al., 2022). Its multi-user functionality, real-time interaction capabilities, and diverse set of design-oriented features have contributed to its growing preference among design teams and educators.

Despite the widespread use of online whiteboards and cloud-based platforms in fostering collaborative learning environments, existing literature largely focuses on their general applications in education and interdisciplinary teamwork. There remains a significant gap in research addressing the specific ways in which student design teams utilize design-oriented and customized online whiteboards to support their creative workflows. Understanding how these tools can be tailored to architectural education, particularly in the context of iterative design processes, visual collaboration, and peer learning, is crucial.

3. Collaborative Design Infrastructures in Cloud-Based Platforms

This study aims to closely examine the interfaces of cloud-based collaborative platforms and assess their contributions to co-design processes, particularly within the context of architectural design studios. These platforms enable design teams to collaborate remotely and in real-time, supporting a decentralized and flexible workflow that is especially advantageous for student teams working outside traditional studio settings. By eliminating spatial constraints, cloud-based tools foster more inclusive and agile design interactions.

This paper prioritizes qualitative insights derived from the use of Miro Online Whiteboard, a platform that has gained increasing traction in collaborative architectural practices. While Miro serves as a focal point for analysis due to its widespread adoption and robust feature set, the study does not aim to promote this specific tool. Rather, it uses Miro as a case study to explore broader implications and emerging possibilities for digital co-design platforms. In the near future, it is likely that more advanced, discipline-specific tools will emerge, better tailored to the unique demands of architectural design and education.

Miro's interface allows participants to seamlessly share visual and textual information, integrating various forms of media such as images, videos, and documents. These capabilities support the iterative development of design ideas, which is especially crucial in competitive settings where time constraints and design clarity are vital. The platform also enables real-time commenting and annotation, fostering immediate peer interaction and responsive guidance from instructors. This type of input is essential for the continuous refinement of design proposals. Furthermore, the ability to create shared boards and collaborative workspaces enhances team dynamics by enabling concurrent engagement with evolving design content. These affordances position platforms like Miro as key infrastructural components in reshaping conventional design collaboration into more distributed, adaptive, and feedback-driven processes suitable for contemporary architectural education.

3.1 Limitations and Development Gaps in Online Whiteboards for Architectural Design Education

While platforms like Miro offer significant advantages in facilitating real-time, visually rich collaboration for design teams, several limitations and gaps persist, particularly when evaluated through the lens of architectural education. These issues highlight the need for more tailored, discipline-specific tools that respond to the complex and layered nature of architectural design learning.

3.1.1 Cognitive Overload and Interface Clutter

The open and real-time collaboration model provided by online whiteboards can unintentionally result in cognitive overload, especially for novice architecture students. When multiple team members simultaneously annotate, sketch, or comment on the same shared space, the interface often becomes visually saturated. This makes it difficult to filter, organize, or prioritize feedback effectively. Such visual and cognitive clutter can hinder the process of convergent thinking, which is essential for refining and consolidating design decisions after the initial idea generation phase.

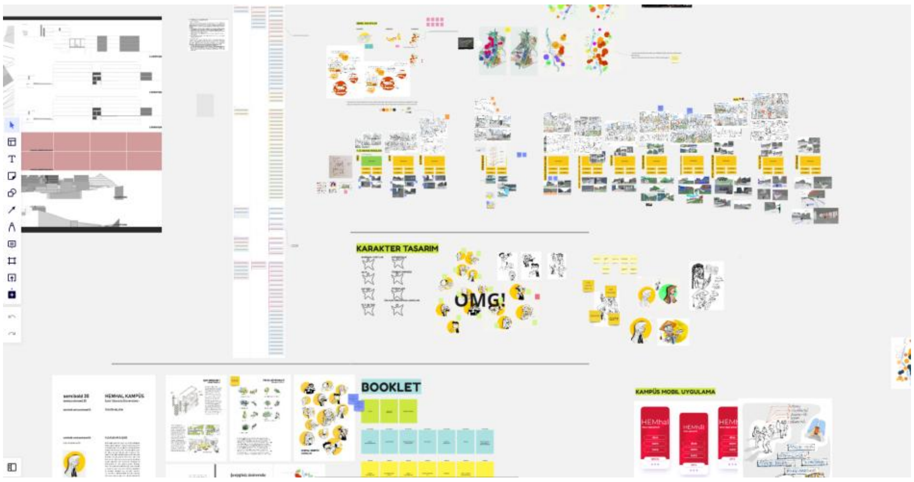

Fig. 1. General overview of a shared student design team whiteboard consisting of images and notations about: user definitions, representational decisions, storyboards, and urban diagrams (source: author)

3.1.2 Lack of Structured Feedback Channels

Although Miro and similar platforms allow commenting and note-taking, they lack more advanced feedback mechanisms such as threaded discussions, layered annotations, or feedback filters based on user roles. In architectural education, where continuous and structured instructor feedback is essential for refining design outputs, the absence of these features presents a major limitation. Tools that allow categorizing comments according to design phases, assigning feedback to specific participants, or distinguishing between peer and instructor inputs could significantly enhance the educational value of these platforms.

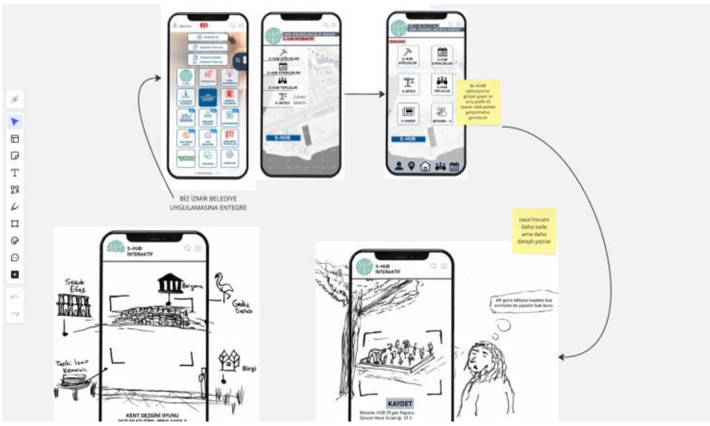

Fig. 2. Sticky notes and arrows as feedback affordances between instructor and architecture student (source: author)

3.1.3 Limited Integration with Architectural Software

Another significant limitation of current online whiteboard platforms is the inadequate integration with essential architectural design tools, such as AutoCAD, Revit, Rhino, and SketchUp. Presently, these platforms mainly support the upload of static exports, such as images or PDFs, which hinders the dynamic and iterative nature of architectural design processes. The absence of native support for editable and interactive file formats restricts the potential of online whiteboards to function as a seamless, integrated design environment. Ideally, these platforms should allow for the coexistence and simultaneous evolution of conceptual sketches, representational drawings, and technical models within a shared collaborative space.

To address this gap, future software development could focus on establishing deeper interoperability with industry-standard design tools, enabling real-time collaboration on 3D models and technical drawings. Such integration would allow design teams to modify and annotate each other's models, fostering a more fluid and interactive workflow. Additionally, introducing software-specific annotations, pop-up windows, and context-sensitive tools could enhance communication between team members, making it easier to exchange ideas and track design revisions. These enhancements could also play a key role in facilitating peer learning, as students would be able to work on and critique each other’s live models and sketches, simulating a more authentic collaborative design experience. By overcoming this barrier, online whiteboards could evolve into powerful, all-encompassing platforms that support both conceptual and technical design processes, bridging the gap between creative exploration and technical execution.

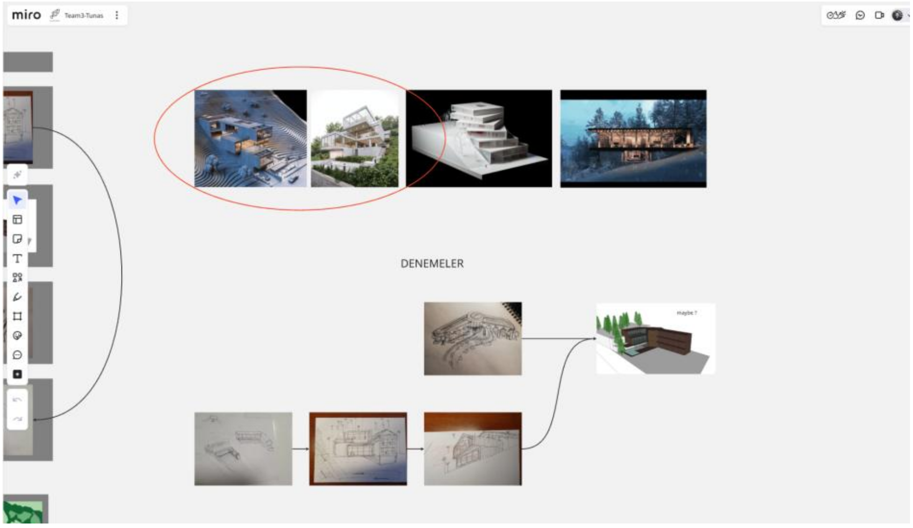

Fig. 3. Screenshots from software interfaces and sketches as the only solution for sharing ideas (source: author)

3.1.4 Insufficient Support for Time Management and Workflow Structuring

Collaborative design projects in educational settings require clear structuring of tasks and timelines. However, most online whiteboard tools lack features such as integrated schedules, task delegation, or phase-based workflows. Without these supports, student teams may struggle with pacing their work or managing group responsibilities. The inclusion of built-in studio calendars, task trackers, or workflow templates would greatly benefit architecture students working in collaborative settings. Although there are some templates for management and planning departments, there are no add-ons or guidelines to facilitate time and work management for students in architecture education.

3.1.5 Dependence on High-Speed Internet and Modern Devices

The effective use of online whiteboards assumes stable internet connectivity and access to up-to-date devices. Students with limited digital infrastructure may experience difficulties in loading complex boards or participating fully in collaborative sessions. Additionally, as boards become more content-heavy, performance issues may arise, particularly on lower-end hardware. These technical constraints create unequal learning conditions among team members and should be considered in future platform developments.

3.1.6 Absence of Architecture-Specific Templates and Tools

Currently, most online whiteboards offer general-purpose tools that are not specifically designed for architectural workflows. Architecture students, however, would greatly benefit from having access to discipline-specific features tailored to their design needs. These could include tools such as scaled grids for accurate drawings, customized drawing templates for plans, elevations, and sections, and mood board layouts to assist with conceptualization. Moreover, support for architectural notation standards, such as dimensioning conventions, section markers, and wall thicknesses, would ensure that students' digital drawings align with established practices in the field.

The addition of specific tools for architectural representation modes is crucial for enhancing the functionality and relevance of online whiteboards in design education. For instance, having human section figures available would allow students to rapidly discuss and communicate the scale of their section drawings, providing a quick and clear visual reference for size and proportion. Plan and site plan annotations could also be incorporated, including tools for marking north direction, adding directional arrows, and creating geographic references. These features would help students present their work in a manner consistent with professional architectural documentation.

In addition, user-friendly tools for texture creation and material representation are essential for conveying the aesthetic and tactile qualities of a design. Features that allow students to apply textures and visualize materials within their digital models would promote a deeper understanding of materiality and spatial experiences. Furthermore, tools for quickly creating architectural posters and presentation templates could be invaluable during jury or critique sessions, enabling students to efficiently prepare visual communication materials that highlight their design ideas while adhering to presentation standards.

Fig. 4. Screenshots from a student architectural design team utilising sketches and other techniques to represent their design ideas (source: author)

3.2 Implications for Future Development and Research

The limitations identified in current online whiteboard platforms underscore the necessity for more architecture-specific collaborative environments. From a software development perspective, these gaps highlight the demand for tailored interfaces that support both divergent and convergent design thinking, structured feedback systems, discipline-integrated workflows, and tools adapted to the representational needs of architectural practice. Developers could collaborate with design educators to prototype features such as layered annotation, CAD/BIM integration, time-managed studio workflows, and cognitive load-reducing visual filters.

From an academic research perspective, these shortcomings offer fertile ground for investigating how digital tools can better align with pedagogical goals in architectural education. Future studies might explore how novice design teams interpret and navigate overloaded interfaces, how structured feedback formats affect learning outcomes, or how cross-platform interoperability can support a more fluid digital design process. Ethnographic and user-experience-based research methods can be especially valuable in understanding how students adapt these platforms to meet their learning needs. Ultimately, addressing these challenges can contribute to the development of hybrid learning ecosystems that are not only more intuitive and inclusive but also more responsive to the evolving demands of architectural design education.

4. Conclusions

This study explored the use of online whiteboards in architectural design education, examining how these platforms support student collaboration and cognitive processes. Online whiteboards provide students with flexible spaces to externalize their ideas and collaborate in real-time, allowing for collective feedback and iterative design. While these platforms encourage collaborative creativity, their effectiveness depends on interface quality and support for students' cognitive engagement. However, some platforms fail to meet the specific demands of architectural education, with features that can overwhelm users or lack crucial design tools. Students often struggle with poorly designed feedback mechanisms and inadequate integration with specialized design software, limiting their ability to fully engage in architectural problem-solving.

The study also found that online whiteboards significantly influence teamwork and problem-solving strategies. They promote simultaneous ideation and creative collaboration, enabling students to break down complex tasks and refine design ideas together. However, the absence of architecture-specific features, such as scaled grids or proper notation tools, hinders students' ability to express and test design concepts effectively. This gap in functionality means that students often rely on general-purpose tools, which can restrict their problem-solving capabilities in the context of architectural design. Nonetheless, when used effectively, these platforms encourage adaptive teamwork strategies and can foster peer learning and real-time problem-solving.

Based on the findings, several key conclusions have emerged regarding the role of online whiteboards in architectural design education:

- **Cognitive Engagement and Feedback Mechanisms:** While online whiteboards can support students' cognitive processes, their effectiveness hinges on interface quality and the presence of structured feedback channels. Platforms should integrate visual filters, threaded discussions, and categorized feedback systems to streamline collaboration and mitigate confusion.

- **Integration with Design Software:** A significant limitation of current online whiteboard tools is their lack of integration with architectural design software like AutoCAD, Revit, and SketchUp. Future platforms should integrate real-time collaboration features with these tools, enabling seamless interaction with editable design models, rather than relying on static image uploads. This would promote a more cohesive design process, facilitating real-time problem-solving and collaboration among team members.
- **Discipline-Specific Features:** The study highlights the need for architecture-specific features that cater to the demands of architectural education, such as tools for architectural notation, section figures for scale discussions, and easily accessible templates for plans, sections, and elevations. These features would make online whiteboards more relevant to architectural education and improve the quality and speed of design iterations.
- **Support for Task Management and Workflow Structuring:** Collaborative design work requires clear task structuring and time management. Online whiteboards should incorporate task management features, such as calendars, workflows, and progress trackers, to enhance the organizational aspects of group projects. These features would help students better manage their collaborative processes, increasing both efficiency and effectiveness in the design workflow.
- **Enhanced Peer Learning Opportunities:** With the right tools, online whiteboards can significantly enhance peer learning by allowing students to annotate and critique each other's work in real time. Future platforms should offer advanced interaction features that enable collaborative modifications to shared design files and facilitate visualizing and communicating design changes.

In conclusion, online whiteboards hold substantial potential to transform architectural design education by fostering collaboration and problem-solving. However, their current limitations must be addressed. Future development should focus on creating more specialized tools to meet the unique needs of architecture students, enhancing platforms' ability to support iterative design processes, structured feedback, and real-time collaboration. By aligning these platforms with the demands of architectural practice and education, they can become more intuitive, embedded, and effective tools for both students and instructors in design studios.

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Exploring the social affordances of physical setting in public open space of higher institution: Case of Ozyegin University Quad

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Abstract. Higher Institutions, such as universities are hubs for learning, but they should also be places where students can socialize, relax, and connect to foster essential skills, promote personal and professional growth, and enhance overall well-being. A university square is one of the open spaces meant to facilitate the above human needs with its spatial characteristics. Considering the importance of mental and social well-being, which is overlooked compared to physical safety during the design of public open spaces, this study investigates the functional diversity through social affordances offered by the physical setting of OzU Quad, a central public space at Ozyegin University. Affordance theory, which explores the relationship between an environment and its potential for user behavior, provides the framework for this research. The study combines in-depth one-on-one interviews with 17 students, and behavioral observations conducted at strategic times of the day. The interview participants represent a diverse range of genders, ages, nationalities, and durations of stay at the university. Data analysis reveals three categories of Quad users: frequent visitors, occasional visitors, and non-visitors. The findings demonstrate a clear connection between the physical design of the Quad and the social activities that take place. The open and spacious central area with diverse features (including fixed, semi-fixed and mobile elements) affords activities like relaxing, socializing, and observing people. Conversely, the completely paved area with limited seating primarily affords walking and smoking cigarettes. The research highlights the importance of considering user needs and preferences when designing public open spaces. Understanding the social affordances offered by the physical environment can help universities to create spaces that foster desired social interactions and enhance the overall campus experience.

Keywords: Affordance theory; Behaviour; Physical setting; Public open space; University square

1. Introduction

Social cohesion - the strength and quality of relationships and the sense of solidarity among members of a society-, well-being, and sustainability are essential interconnected concepts that shape the development of vibrant and equitable communities. In higher education institutions, public open spaces are more than just areas for physical movement or rest—they serve as critical sites for social interaction, creativity, and the development of a sense of community among students, faculty, and visitors. The design of these spaces plays a significant role in shaping how individuals engage with one another and their environment. Public spaces that are thoughtfully designed and that foster interaction are essential to the social fabric of campus life.

One framework that addresses the potential of these spaces is *placemaking*, a collaborative and inclusive approach that focuses on creating meaningful, engaging environments that reflect the values, culture, and needs of the people who use them. According to Madden (2021), placemaking goes beyond simply improving aesthetics or function—it seeks to transform public spaces into places that resonate with people on a deeper level, encouraging social connections, fostering a sense of identity, and supporting the ongoing evolution of the community. In the context of higher education, placemaking can help transform an ordinary campus courtyard or plaza into a vibrant, dynamic area that strengthens relationships and promotes collaboration (Kong & Zheng, 2023). Common challenges of public open spaces often include underutilization, limited participation, and inadequate consideration of users' well-being. In many cases, certain areas within public spaces, such as the University Square, remain underused due to various factors, with some community members, like students, not fully engaging with these spaces. This lack of participation can result from barriers related to accessibility, design, or the surrounding

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environment, leading to spaces that do not serve the diverse needs of the population (Project for public spaces, 2009). Additionally, the mental health (Myers, Mabey, & Burleson, 2024) and well-being of users (Zhang, 2024), especially in spaces frequented by students, are commonly overlooked in the design and planning process. These challenges highlight the need to address the factors behind underuse, promote inclusivity, and consider the mental and emotional benefits of public open spaces to foster a more vibrant, accessible, and supportive environment for all users. In this sense, Gibson's affordance theory (1979; 2014) serves as an important perspective for the situation. The concept of affordances, according to Norman (1999), was introduced by ecological psychologist James J. Gibson in the 1970s. It helps us understand the relationship between an environment and an organism's capabilities for action.

Despite existing literature on public space design, there is a gap in understanding how affordances can influence student well-being and sustainability in these spaces. This paper adds to the expanding body of interdisciplinary research focused on measuring affordances as a means to enhance placemaking and support the Sustainable Development Goals within public urban spaces. By offering a qualitative evaluation of young people's behaviour and experiences in various contexts, our discussion emphasizes how affordances in public green spaces can illuminate the complex connections between student's well-being, environmental usage and sustainability, particularly in educational settings.

2. Literature review

2.1. Social Cohesion, Placemaking, and Public Space Design

Social cohesion is frequently seen as being jeopardized by the growing cultural and economic disparities in modern societies, along with the intensifying pace of urban life. As the primary setting for social interactions among strangers, public space plays a significant role in either promoting or hindering social cohesion. The first effort to compile scholarly knowledge at the intersection of public space design and social cohesion was Aelbrecht and Stevens (2018), offering a global perspective on research and urban design practices in both the Global North and South. It brings together contributions from leading and emerging scholars and practitioners from both regions to explain what precisely 'social cohesion' means, how it is experienced in public spaces, and what impact the design of urban areas can have on fostering or hindering it. Public space plays a vital role in our social lives by contributing to people's attachment to their cities, neighbourhoods and local communities, creates opportunities for social interaction, social mixing, inclusion and community building, and supports people's well-being and individual and group identities (Amin, 2008). However, despite efforts by social scientists to identify them, clear answers on achieving social cohesion remain elusive (Aelbrecht & Stevens, 2018). Aelbrecht and Stevens (2018) further identify five important themes which include the emerging typologies of public spaces, symbolism and sense of belonging, design elements that encourage social interaction, processes of engagement and placemaking, and reflections from urban design practice. These themes offer a diverse perspective on how public space design influences social cohesion.

Regarding what makes a great place, Kathy's (2021) *Principles for Creating Great Community Places* further stress the importance of community involvement, thoughtful design, and continuous improvements to create vibrant public spaces. The first principle underscores the value of engaging the community as experts to ensure that the space reflects their needs and values. Rather than focusing solely on design, the objective should be to create a functional "place" that encourages interaction and connection. Collaboration with partners, observing how people use the space, and implementing minor, affordable improvements are critical to success. A clear, community-driven vision helps shape the space's purpose and identity, while the ability to adapt over time is essential as needs change. Ultimately, these principles highlight that creating exceptional public spaces is a continuous process that requires creativity, attention, and a commitment to evolving alongside the community's needs.

One of the challenges regarding social cohesion is the division between sociological and urban design research, with some studies focusing solely on the sociological aspects of social life while others focus on the physical attributes of public spaces (Aelbrecht & Stevens, 2018). Another issue is the lack of knowledge exchange between urban design theory and practice, as well as the limited integration of scientific knowledge into environmental design disciplines. A need to look at the issue holistically is paramount.

2.2. Well-Being and Mental Health in Public Open Spaces

Well-being and mental health of the users in public open spaces are of utmost importance. There is a growing body of literature showing how the design of physical open spaces influences the health outcomes of the user (Myers, et al. 2024; Nissen, *et al.* 2020) and productivity of students (Darma, Arshadi, Cumurcu & Mizrak, 2023). Traditionally, design disciplines have not been focused on public health, but there is a growing recognition of the role designers play in promoting or hindering health. An example includes the assertion of the "United States Surgeon General at the 2014 Design + Health Summit" that architects should be viewed as "public health workers." (Myers, et al. 2024). The World Health Organization (2020) defines health as a comprehensive state of three dimensions; physical, mental, and social well-being. It emphasizes that the right to enjoy the highest standard of health is a fundamental human right, irrespective of race, religion, political belief, or any economic or social status. The simplified definitions of the three dimensions were tabulated by Myers, et al. (2024) as shown in Table 1.

Table 1. Definitions and examples of measures of health dimensions (Myers, et al., 2024)

Health dimensions	**Definition**	**Existing measures and metrics**
Physical	Bodily health and abilities	Mortality, disease, self-reported general health.
Mental	Emotional, psychological, and cognitive	Depression, positive and negative affect, attentional function, cognitive decline, dementia.
Social	Relationships and interactions within society	Perceived social cohesion, reciprocity, loneliness, social networks.

Table 2 below summarizes key findings from recent literature on mental health and design elements of public open spaces such as parks, squares and other green spaces and their contribution to psychological restoration, social interaction, and overall quality of life.

Table 2. Key Findings from recent literature on Public Space Design and Health (Source: Authors).

Design Element	**Key Findings**	**Citation**
Green Spaces	Exposure to green spaces reduces stress and alleviates anxiety and boosts productivity.	(Bressane et al., 2024; Darma et al., 2023; Shahmiri et al., 2024)
Natural Elements (Water features etc)	Higher degrees of naturalness in green spaces correlate with lower mental distress.	(Bressane et al., 2024)
Sensory Design	Multi-sensory experiences in green spaces enhance psychological restoration.	(Qu & Ma, 2024)
Accessibility & Inclusivity	Inclusive design that caters to diverse populations enhances well-being.	(Addas & Maghrabi, 2021; Ziersch et al., 2023)
Physical Activity & Social Interaction	Public spaces that promote physical activity and social interaction improve mental health.	(Addas & Maghrabi, 2021; Livingston, 2024)

Myers, et al. (2024) also explore a variety of design approaches aimed at improving holistic health outcomes by prioritizing the involvement of multiple stakeholders in the design process. Approaches like design for well-being and people-centered design focus on enhancing physical, social, and emotional well-being, emphasizing inclusivity and equity. Methods such as human-centered design (HCD) and participatory design involve end-users in the design process to ensure their needs and values are considered, which can enhance well-being. However, these approaches have limitations, including criticisms of their focus on privileged groups and the potential harm of poorly executed participatory methods. There's a need for a deeper theoretical understanding of how specific design choices impact health outcomes, particularly for vulnerable populations, to ensure that design practices lead to improved health and well-being.

2.3. Affordance Theory and Public Space Interaction

Scholars in man-environment studies have made significant efforts to establish a relationship between human behavior and the environment by examining how physical, social, and cultural surroundings influence human actions and well-being (Barker, 1968; Norman, 1999; Rapoport, 1977). They have explored various interdisciplinary fields like psychology, sociology, geography, anthropology and environmental science to understand how people perceive, interact with, and are affected by their environments. This includes topics like environmental stress, urban design, place attachment, and how natural or built environments can impact emotions, productivity, and social behavior. One promising concept among such efforts, especially for exploring experiences of individuals, is Gibson's affordance theory (Myers, et al., 2024). The literature indicates that applying Affordance Theory to environmental design has the potential to enhance the functionality and experiential quality of spaces for human users (Li, 2013). In 1979, psychologist James Jerome Gibson developed the theory of affordance to explain how individuals respond to the physical characteristics of their environment. He defined affordances as what the environment offers to individuals, regardless of their needs or perceptions. Fig. 1 shows the basic and original concept of affordance adopted from Li (2013). Affordances are invariant, always present, but may be perceived differently depending on the observer's needs and capabilities. For instance, a flight of stairs affords ascending to the next floor, but an infant who cannot climb stairs would not perceive this affordance. Gibson also introduced the concept of "niche," which he describes as how a species lives, not only where it lives, suggesting that a niche consists of a set of affordances (Heras-Escribano & Pinedo-García, 2018). He noted that humans modify the environment to create more positive affordances and fewer negative ones. In public space design, affordances include paths that enable pedestrian movement and separate traffic, or parks that provide space for physical activity and social gatherings. Some affordances are positive, like a park's recreational benefits, while others can be negative, such as a park that separates socioeconomically distinct neighborhoods (Li, 2013).

Affordance theory has been expanded through various classifications proposed by different researchers. Reflexive, reactive, and reflective affordances were introduced by Kannengiesser and Gero (2012). Reflexive affordances require minimal internal processing; reactive affordances result from a deliberate search process; and reflective affordances are exploratory in nature. These categories build upon hidden and false affordances, earlier proposed by Gaver (1991). Real and perceived affordances, as described by Yilmaz, Mumcu, and Cigdem (2017), distinguish between the designer's intended functionality (real) and the user's interpretation of possible actions (perceived). Passive and active affordances, introduced by Ozbil, Ozgur, Mujesir, and Kenan (2018), are defined based on the level of user interaction—passive being static possibilities and active requiring user engagement. Finally, improvised and serendipitous affordances, identified by Stevens, Dalay, and Dovey (2023), refer respectively to those that emerge through user adaptation and those that arise unexpectedly by chance. Ciavola and Gershenson (2012) explains how affordance theory aligns with function-based design. However, despite these advances, affordances are rarely mentioned in product design processes. Some criticisms suggest that affordances are too abstract and ambiguous for practical implementation (Myers, et al., 2024). Davis (2020) outlined mechanisms and conditions of affordances (Fig. 2), providing insights into how designers can influence desired affordances.

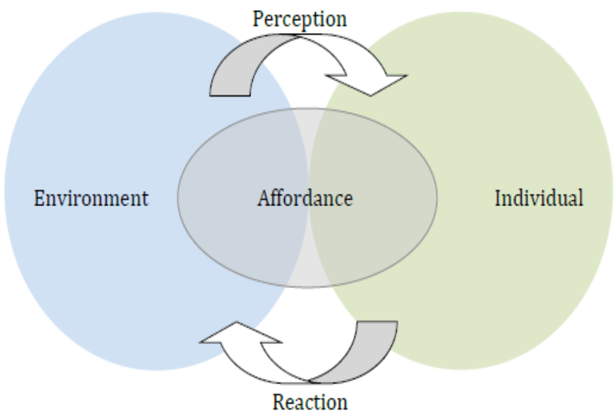


Fig. 1. The original concept of affordance (Source: Li, 2013).

Fig. 2. Davis (2020)'s mechanisms and conditions of affordances.

Scholars have also proposed Affordance-Based Design, which shifts focus from functions to affordances, most of them examining the relationship between physical activity and objectively assessing built environment, and improving the space's condition (Smith et al., 2017). Despite its potential, affordance theory remains underutilized in renovation design practices.

According to Nissen et al. (2020), early research on youth and urban affordances focused on the functional aspects of the environment, examining the opportunities and restrictions local places offer to young people. While this approach remains prominent in some urban design research, Nissen et al. (2020) acknowledge that later work by Clark & Uzzell (2002) and Kyttä (2002) introduced a more socially, emotionally, and culturally informed concept of affordances. From this perspective, the environment's physical aspects are seen as foundational to experiences, best understood through local knowledge, social behaviors, and norms. Affordances are understood as the meaningful relationships that arise between an individual's perceptual and action capabilities and the features of the surrounding environment. This approach challenges the subject-object dichotomy, recognizing affordances between the individual and the environment. For instance, Clark & Uzzell (2002) assessed local environments based on what they afford residents, such as opportunities for activity, enjoyment, safety, or social interaction. Examining affordances offers a deeper understanding of the relationship between youth and their urban surroundings, moving beyond simple descriptions to explore why certain preferences exist (Li, 2013).

Kaaronen proposes that integrating affordance theory into sustainable development raises critical planning questions, such as: *Which affordances are encouraged, restricted, or neglected, and how do these decisions shape everyday behavior?* Additionally, other scholars emphasize that social inequality significantly influences young people's access to urban affordances (Nissen et al. 2020). This theory focuses on spatial relationships and flow, demonstrating that public spaces can be analyzed beyond physical elements. Several key factors related to environmental affordances have been identified in the literature. Several previous studies, according to Abu Elkhair, Sarhan and Bayoumi (2023) have identified five key social qualities that influence the use of outdoor spaces: (1) the effectiveness and diversity of social activities, (2) the diversity of users, (3) the design and enclosure of surrounding buildings, (4) the accessibility of pedestrian movement lanes, and (5) the density of vegetation, including tree planting and shading elements. The social and cultural context of the environment plays a role in shaping affordances. Shared norms, activities, and meanings associated with a space can enable or constrain certain behaviors and interactions (Rietveld, Haan, & Denys, 2013). On the other hand, people's characteristics, experiences, and intentions can also influence how they perceive and respond to the affordances in their environment. Factors like age, personality, and familiarity with a space have been found to mediate affordance perceptions (Bagais, n.d.). Studies have found that elements like density of plantings, enclosure, availability of seating, and presence of community gardens can all impact the social and recreational affordances perceived by users (Almadina & Marcillia, 2024; Hadavi, Kaplan, & Hunter, 2015; Şen et al. 2020). Other important factors, including sensory dimensions like water features, universal design, safety, and ease of navigation have all been shown to influence affordances, especially for children and those with disabilities (Bagais, n.d.; Guo, Shi & Chen, 2023). Ozbil et al (2018) quantitatively investigated factors affecting occupation patterns in the open spaces of Ozyegin University in Istanbul. The study concentrated more on the population of the users -not the affordances- and considers the whole university setting. However, this study aims to focus on the affordances, behavior richness, and usage pattern specifically of the OzU Quad, as it has distinct characteristics from the other outdoor areas in the university.

3. Methodology

Affordances theory has its roots in e*cological psychology* - which focuses on the interactions between people and their environments - (Norman, 1999). It has also been seen in the literature that affordances are not limited to the environment or objects alone. Morgenthaler et al. (2022) explain that affordance theory acknowledges the agency of the physical environment from a transactional perspective, where the person and the environment are equally important in shaping human behaviour. This suggests that the best way to deal with affordances is to look at both the person and their environment. Looking at the person means to look at their behaviour in the environment. On the other hand, looking at the qualities of the environment may include both tangible and intangible qualities. This study used observation (both behavioural and environmental), along with interviews to explore the social affordances that contribute to the social well-being of students in public open spaces in higher institutions, and to sought explanation as to why the problems of concentration of behaviour, underusage, over-usage, social cohesion and inclusivity of the environment occur despite the designers' efforts to address them during the design phase. For this purpose, Özyeğin University was selected as the study area, and ethical approval was granted by the university's committee on research ethics.

3.1. Study Area

The study area is Ozyegin University Central Square (OzU Quad) which is the heart of the Çekmekoy Campus, located in Nişantepe, Cekmekoy on the Asian side of Istanbul in Turkey (Fig. 3). Özyeğin University (OzU), established in 2007, was initially situated in its Altunizade Launch Campus, and moved to its Çekmeköy Campus in 2011 (Ozbil et al, 2018). The campus main entrance gate is located along Orman Street, which can be accessed through Saray Street that is connected to Şile Highway at the two ends (Ekşioğlu Mah. and Nişantepe Orman Park traffic circle).

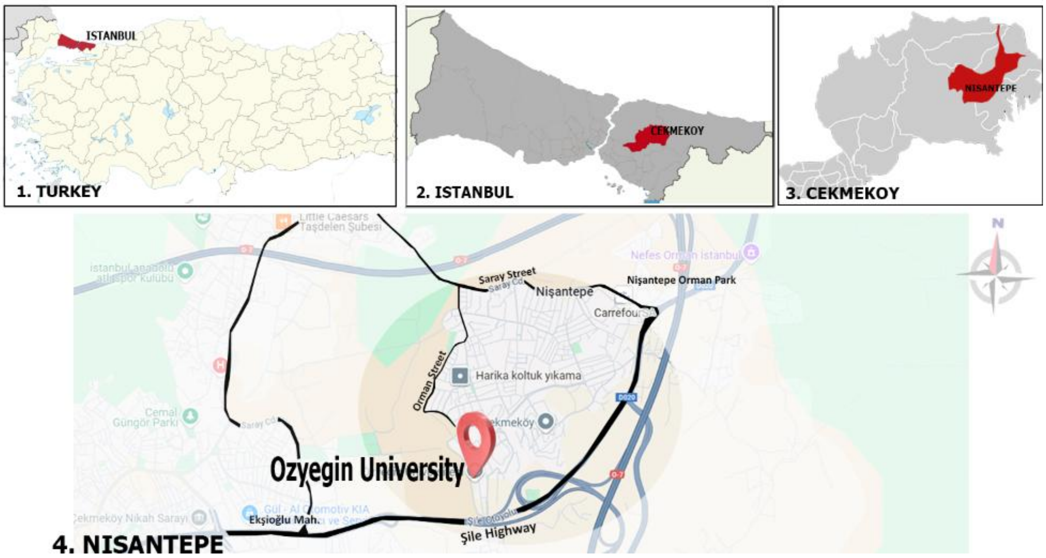


Fig. 3. Maps showing the Location of the University (Source: Authors).

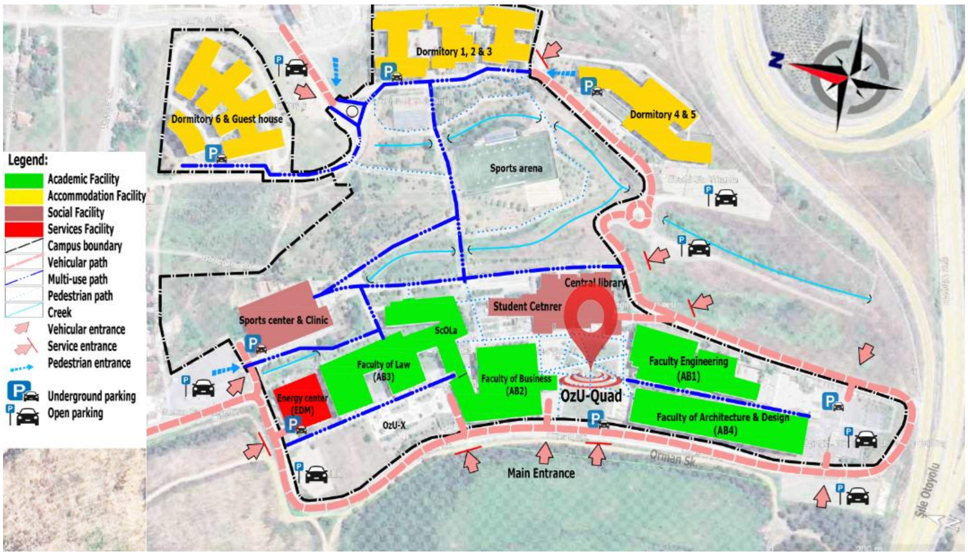


Fig. 4. Land use map of Ozyegin University Campus (Source: Authors).

The campus spans a total area of 283,264.9 square meters, with 132,946.1 square meters (about 47%) dedicated to open spaces. It consists of various facilities designed to support academic and social interactions, such as modern classrooms, laboratories, a sports center, and communal areas essential for fostering social engagement and collaborative learning among students. The university offers 25 undergraduate programs, 36 graduate programs, and 10 doctoral programs, with a student body comprising 6,261 undergraduates, 570 graduate students, and 194 postgraduate candidates with 529 full-time faculty members (Ozyegin University, 2024). Fig. 4 below shows the land use within the boundaries of the campus.

The OzU campus's main identifiable features are its modern buildings on a sloping terrain (Ozbil et al., 2018). The setting is surrounded by a wire fence and is enclosed by 11 vehicular gates (including service gates), with the main gate located on the west along Orman Street and other gates strategically located all around the boundary, each connected to the 14 parking spaces -both open and underground parking spaces. There are 3 pedestrian entrances - at the main gate, near the sports center and at the hostel area. The land use configuration is mainly divided into 3 along the east-west axis -Accommodation on the East, sports at the center, and Academic on the West- all connected using a multi-use pathway. The OzU quad is in the heart of the academic area, surrounded by the students' center, central library, faculty of engineering (AB1), faculty of architecture (AB4), and faculty of business (AB2).

OzU Quad serves as an outdoor meeting point for students and faculty alike because it is the intersection of all faculties where students meet and enjoy outdoors, share a cup of coffee with friends, study, or relax between classes. At the same time, host concerts and other vibrant activities of students' clubs. This area is highly integrated with the other parts of the campus (Şen et al., 2020; Ozbil et al., 2018). As shown in Fig. 5, it can be accessible by pedestrians, including physically challenged, from both the surrounding buildings and the connected pathways from other parts of the campus.

The total area of the Quad is measured to be approximately 8,355m^2, comprising the areas. For the sake of analysis, the Quad area was divided into six portions as shown in Fig. 6 below: Student center entrance (Q1), Faculty of Engineering entrance (Q2), Central area (Q3), Faculty of Business bank (Q4),Lower quad (Q5) and the Faculty of Architecture entrance (Q6).

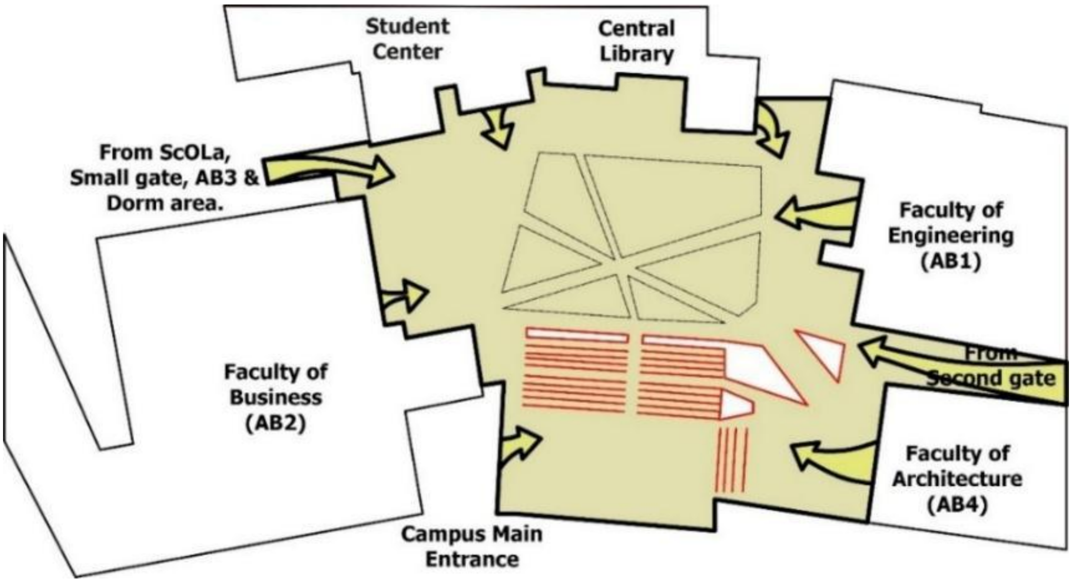


Fig. 5. The OzU Quad Accessibility (Source: Authors).

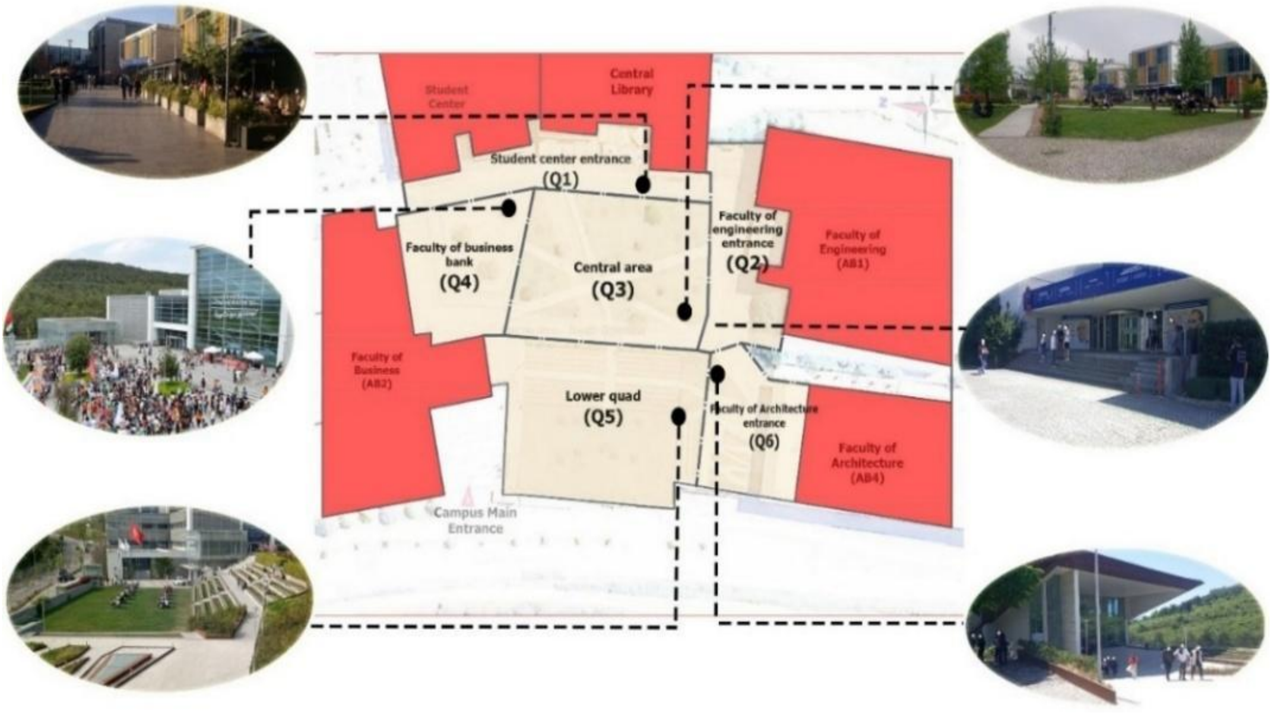


Fig. 6. Division of the OzU Quad into six parts (Source: Authors).

Table 3. Summary of the characteristics of the 6 parts (Source: Authors).

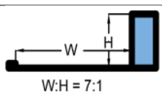
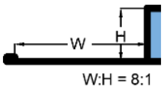
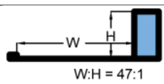
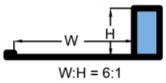
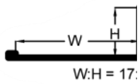
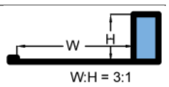
Space name/Characteristics	Student center entrance (Q1)	Faculty of Engineering entrance (Q2)	Central area (Q3)	Faculty of Business bank (Q4)	Lower quad (Q5)	Faculty of Architecture entrance (Q6)
Area (m2)	 1,139	 997	 2,020	 1,134	 2,335	 1,196
Accessibility	-Student center -Café Nero -Central Library -Scola/hostels -Q3, Q4 and Q2	-Faculty of Engineering (AB1) -Central Library -Q1, Q3 and Q6	-Q1, Q2, Q3, Q4, Q5 and Q6	-Faculty of Business (AB2) -Q1, Q3 and Q5	-Campus main entrance -Q3 and Q6	-Faculty of Architecture (AB2) -Q1, Q3 and Q5
Circulation/ movement type	Axial pathway completely paved (about 6.7m wide) with flowerpots by the side separating it from Café Nero.	Wide (10m in width) paved area flat area with no definition of specific walking area.	Linear walkways (1.8m to 3m wide) converging at the centre linking all the remaining parts of the quad.	Undefined walkways (paved completely) with 5 steps (0.1m each) along each direction.	Connected to the other parts using stepped walkways, while 1.7m walkways integrated in the stepped spectator's seating area.	8m wide stepped walkway connecting it to Q2, while the rest of the is paved.
Degree of enclosure						
Vegetation cover (%)	2	16.7	60	4.3	54.4	14
Shading area (%)	33	32	3	4.3	0	52
Furniture/objects (type/ quantity)	 3	 3	 17	 20	 10	 3
	 55		 4 (23meter each)	 3	 25 (18meters each)	
	 11	 1	 1			

Table 3 continued

	 **3**	 **3**	 **6**	 **3**	 **3**	 **2**
Material usage (flooring)	-Ebony granite stone	-Natural stone -Cobblestone -Shrubs	-Natural stone -Grass -Wood	-Natural stone -Cobblestone -Wood	-Natural stone -Wood -Grass	-Granite -Steel -Glass -Grass

3.2. Behavioural Observation

In this study, behavioral observation—a systematic observation method and an effective tool for recording both stationary and dynamic human activities, as well as social interactions in outdoor spaces (Abu Elkhair et al, 2023)—was employed. The data was presented through tables and people-centered maps, which use cartographic techniques to capture patterns of social tasks and outdoor space use. The exercise was designed for a period of five workdays. The observations took place on Tuesday, April 16th, 2024; Wednesday, April 17th, 2024; Thursday, April 25th, 2024; Friday, April 26th, 2024; and Monday, May 6th, 2024 (intentionally excluding the weekends), this is to enable the observations to cover both students living on and off campus. The study is mainly interest in observing as much as possible variety of behaviours and activities, therefore observations were scheduled three times a day: mornings (9:00-10:00), lunches (12:00-13:00), and evenings (16:00-17:00), totalling 15 observation sessions -these are peak usage period of the spaces as it coincide with morning breaks, launch breaks and lecture closing periods respectively- although not primarily concern with population. Another important issue is the ability to observe and record in all 6 parts of the quad within a very short period. Since the study deals with both active and passive behaviours, there is a need to cover all portions within a short period of time, because the change in behaviour or even position may occur, which can cause double counting and distorted mapping. However, video recording and picture taking were employed to reduce such challenges, which were handled ethically by keeping safe and ensuring that none of such recording is disclosed to the public. The observations recorded all behaviours including; individual -such as using mobile phone- and group -such as club events-, regardless of all other categorization; Real affordances and Perceived affordances (Yilmaz et al., 2017), passive and active (Ozbil et al., 2018), Improvised and Serendipitous (Stevens et al., 2023), however, *dominant* (those that occur many times), and *present* -those that occurred few times- (Bechtel, 1989) were later sorted out for analysis. As shown in Fig. 7, the following affordances were observed as individual behaviours in each of the six portions of the quad; *walking/standing* were put together as one behaviour; *sitting* on a bench, lawn or any other object/surface; *Sunbathing*, those laying down under the sun on any surface or object; *eating* any kind of food; *drinking coffee*, for those holding any drink container; *observing people and activities* meant for those looking at one places in a thinking posture; *Listening to music* is for those wearing earpiece/headphones; *smoking*, holding any type of cigarettes; *Taking pictures*, holding/posing with a camera or mobile phone; *Using mobile phone* for those on phone call, or looking at computer, phone or tablet screen; *reading* for those holding/looking at any type of paper. There are also instances when more than one behaviour was observed in the same place and time, the situation termed "niche" by Gibson (Li, 2013). Some group activities recorded include meeting with friends, sports/gaming, club activities, music/dance performances, International/cultural events, and campus activities, such as homecoming not located on the map but separated in a table presented in the results section.

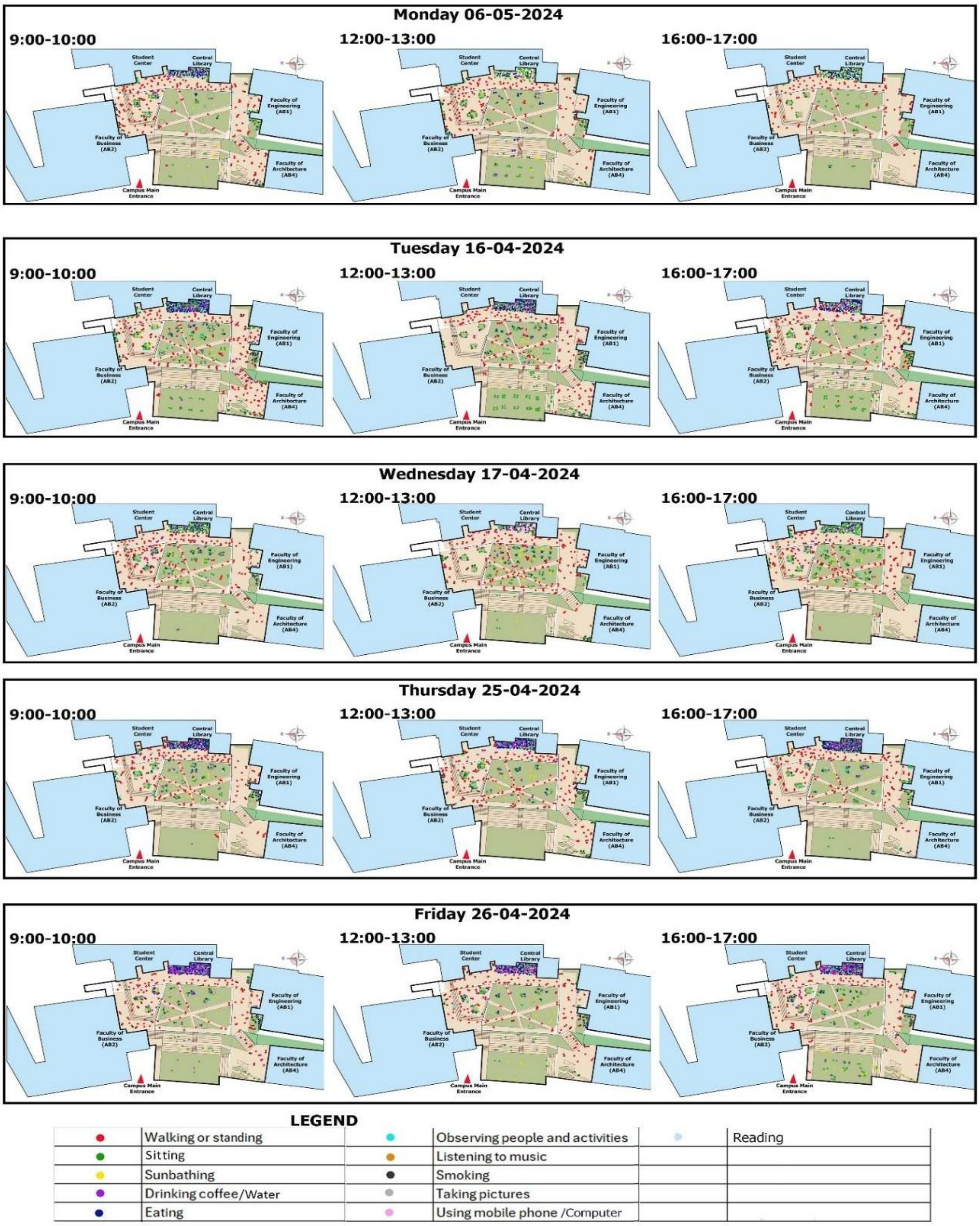


Fig. 7. Behavioural mapping of observed behaviours (source: Authors).

3.3. Survey/Interview

The study was limited to only the students of the Ozyegin University because they make the highest population of users in the space (Ozbil et al., 2018), and no age or gender restriction whatsoever. An interview was conducted to 17 students randomly selected from various departments and nationalities both physical (7 participants) and online (10 participants), the choice for online or physical is attached to the interest of the participants. As the online participant avail their contacts for online participation for reasons only known to them. This interview was made up of 12 guiding open-ended questions regarding students' satisfaction and mental well-being of the quad, the participants were asked to take part in one-on-one chat sessions lasting about 20 to 35 minutes. Based on their consent, they were asked to share their experiences and perceptions of the OzU Quad regarding the spatial configuration, physical elements, design and activities in the spaces (excerpt of the data is presented in the data presentation section). The data was analysed using thematic analysis to identify common ideas.

4. Results

4.1. Behavioural observation result

The overall observed activities across six Quad portions (Q1 to Q6) revealed varied patterns of space use. Walking or standing was the most frequent activity overall, particularly in Q1 (473) and Q3 (307). Eating and drinking coffee were also prominent, especially in Q1, with 475 instances of eating and 350 of drinking coffee. Sitting was highly observed in Q3 (194) and Q5 (133), indicating preferred zones for rest. Sunbathing was most common in Q3 (106) and Q5 (46), suggesting these quarters provided favorable conditions for relaxation. Smoking had notable peaks in Q2 (131) and Q4 (154), while the use of mobile phones or computers was fairly distributed, with the highest count in Q5 (59). Observing people and activities, though less frequent, was observed most in Q4 (50). Less common activities included taking pictures, listening to music, and reading, with the latter being the least observed across all quarters. This has been graphically illustrated in Fig. 8 below.

Table 4. Cumulative observed behaviours for each portion Q1 to Q6 (Source: Authors).

Behaviours/Spaces	Q1	Q2	Q3	Q4	Q5	Q6
Walking or standing	473	198	307	276	6	118
Sitting	107	25	194	113	133	25
Sunbathing	8	4	106	16	46	4
Drinking coffee	350	36	95	54	15	11
Eating	475	19	88	19	4	0
Observing people and activities	54	22	38	50	2	1
Listening to music	7	8	29	6	1	0
Smoking	89	131	53	154	1	52
Taking pictures	12	15	15	10	3	4
Using mobile phone/computer	99	35	49	45	59	10
Reading	11	5	6	4	2	0

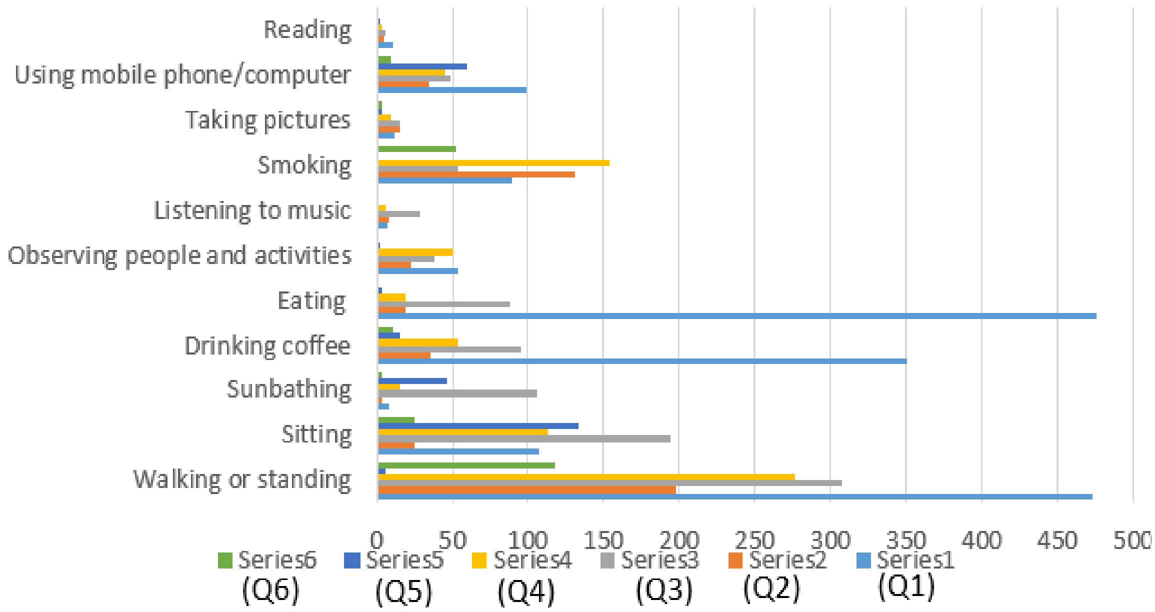


Fig. 8. Behavioral counts and the spaces (Source: Authors).

From another perspective, an analysis of behavioral variety across the six quarters reveals distinct differences in how each space is used. Portion 1 (Q1) demonstrated the highest diversity and volume of activities, with high counts in walking or standing (473), eating (475), drinking coffee (350), and mobile phone/computer use (99), indicating it as a highly active and multifunctional space. Portion 3 (Q3) also showed a wide range of behaviors, particularly in sitting (194), sunbathing (106), and moderate levels in most other activities, suggesting it supports both relaxation and light social engagement. Portion 4 (Q4) exhibited a balanced mix of behaviors with noticeable counts in smoking (154), observing people (50), and sitting (113), reflecting a socially interactive environment. In contrast, Quarter 2 (Q2) had fewer types of high-frequency activities, dominated by walking or standing (198) and smoking (131), suggesting a more transitional or utilitarian use. Portion 5 (Q5) showed specialization in more passive behaviors such as sitting (133), sunbathing (46), and mobile phone use (59), indicating it may offer comfort or amenities conducive to longer stays. Portion 6 (Q6) exhibited the lowest activity levels and behavioral variety, with only modest counts across most categories, suggesting it may be underutilized or less inviting for diverse public use.

4.2. Evaluation of the sub-areas.

Student Center Entrance (Q1) **-**Fig. 9**-** is an area totalling 1,139 m² (7:1 floor to wall ratio), which connects to the Student Center, Café Nero, Central Library, Scola/hostels, and Quad portions Q2–Q4. With an axial, clearly defined 6.7 m-wide paved pathway – finished with ebony granite stone- with flowerpots, making a 2% vegetation cover separating pedestrian space from Café Nero. The 33% shaded area of the portion has 55 outdoor dining chairs, 11 wooden garden chairs and 3 backless metal benches with quite several ashtrays. This area acts as a transitory threshold between social, academic, and commercial spaces. The strong axial pathway ensures efficient pedestrian movement, while minimal vegetation and furniture indicate a focus on circulation over lingering. Despite limited greenery, decent shading (33%) offers some environmental comfort. This has been demonstrated by the highest diversity and volume of activities recorded, with high counts in walking or standing.

The Faculty of Engineering Entrance (Q2) in Fig. 10 occupies an area of 997m² and serves as a primary access point to the Engineering building (AB1), the Central Library, and adjacent zones including Q1, Q3, and Q6. It features a wide, flat 10-meter paved surface made of natural and cobblestone materials, with shrubs adding subtle greenery (8:1 floor-to-wall ratio). However, the space lacks defined walkways, resulting in a broad open layout that allows flexible circulation but may reduce clarity in pedestrian movement. With a moderate vegetation cover of 16.7% and shading at 32%, the environment offers a fair level of comfort, although the presence of only three furniture units limits opportunities for rest and interaction. According to the observed data, this portion had fewer high-frequency activities, dominated by walking or standing and smoking, suggesting a more transitional or utilitarian use.

Fig. 9. Views of the Student Center entrance (Q1) (Source: Authors).

Fig. 10. Views of the Faculty of Engineering Entrance (Q2) (Source: Authors).

Fig. 11. Views of the Central Area of the Quad (Q3)(Source: Authors).

Fig. 12. Views of the Faculty of Business bank (Q4) (Source: Authors).

The Central Area (Q3), Fig. 11, spans 2,020m² and stands out as the most interconnected zone on campus, linking all other major spaces from Q1 through Q6. Its circulation is defined by a network of linear walkways ranging from 1.8 to 3 meters wide, converging at the center to create a strong sense of orientation and movement. The area is open (with floor-to-wall ratio of 47:1) and notably lush, with a high vegetation cover of 60%, which enhances its visual appeal and environmental quality. However, despite its greenery, shading is minimal at just 3%, leaving the space largely exposed to sunlight, particularly during hot seasons. Q3 is well-furnished with 17 seating units of movable picnic benches and fixed wooden platforms, encouraging various social behaviors. The presence of natural stone walkways, grass, and wood contributes to a warm and inviting atmosphere. Observations indicate diverse activities taking place here, including sitting, sunbathing, and moderate social engagement, positioning Q3 as both a dynamic movement hub and a relaxing green oasis.

The Faculty of Business Bank (Q4), an area that covers 1,134m² and is defined by a relatively high degree of enclosure, with a floor-to-wall ratio of 6:1. It connects directly to the Faculty of Business (AB2) and neighboring zones Q1, Q3, and Q5, making it a moderately accessible space within the campus layout. The entire area is paved and features five shallow steps (0.1 meters each) on three sides, contributing to a sense of layered movement but potentially posing challenges for universal accessibility (Fig. 12). Vegetation and shading are limited at just 4.3%, which may affect user comfort during hotter parts of the day. Despite this, Q4 is densely furnished with 20 fixed and movable seating units (metal and wooden backless benches), making it one of the more populated zones in terms of furniture. The material usage—natural stone, wood, and patches of grass—adds texture and warmth to the space. Observational data indicate a socially active environment, with high instances of sitting, people-watching, and smoking, suggesting that Q4 functions effectively as a social pause point, particularly suited for short-term stays and casual interactions.

The Lower Quad (Q5) spans a generous area of 2,335 square meters and serves as a key transitional and recreational space, connecting the campus main entrance with zones Q3 and Q6. Its circulation design is defined by stepped walkways, with 1.7-meter-wide paths seamlessly integrated into the stepped spectator seating, creating opportunities for both movement and passive engagement. The space boasts a high vegetation cover of 54.4%, contributing to its visual appeal and sense of calm (Fig. 13). However, it lacks any form of shading (0%), which can significantly impact user comfort, especially during hot or sunny weather. With 10 picnic furniture units distributed across the lawned space and a material consisting of natural stone and wood, Q5 presents a warm and earthy atmosphere. Observations revealed limited behaviours mainly in the passive category, such as sitting, sunbathing, and frequent mobile phone use, suggesting that this area supports relaxed, informal occupancy. Its layout and use patterns indicate that Q5 functions as a multifunctional open space, ideal for resting and potentially hosting casual or impromptu gatherings.

Fig. 13. Views of Lower Quad (Q5) (Source: Authors).

Fig. 14. Views of the Faculty of Architecture entrance (Q6) (Source: Authors).

The Faculty of Architecture Entrance (Q6) covers 1,196 square meters and provides access to the Architecture building (AB2) while connecting to Q2, Q3, and Q5 zones. Its circulation is anchored by an 8-meter-wide stepped walkway leading to Q2, with the remainder of the space fully paved, creating a formal and direct entry experience. The space integrates 14% vegetation cover alongside high shading at 52%, making it one of the more comfortable zones in terms of environmental protection. Material usage—granite, steel, glass, and grass—reflects a contemporary design language (Fig. 14). Despite these qualities, the area contains only three fixed granite seating units, limiting opportunities for rest or social interaction. Observational data recorded the lowest activity levels and minimal behavioral variety, suggesting that Q6, while aesthetically refined and functionally direct, may be underutilized and lacks features that encourage lingering or diverse public engagement.

4.3. Demographic data

The biographic data of the participants shows a good representation of gender, age, cultural background and level of experience and stay at Ozyegin University. Regarding gender, as seen in Fig. 6 above, 52.9% of the participants are female, which is nearly half of the sample size, and the remaining 47.1% are male. In terms of age, the data in Fig. 15 shows that even though there is representation of each age range, most of the respondents (41.2%) are between the ages of 21 and 25, followed by 35.3% which are between 26-30 years, then 31-35 years and those below 20 years each category has 11.8%.

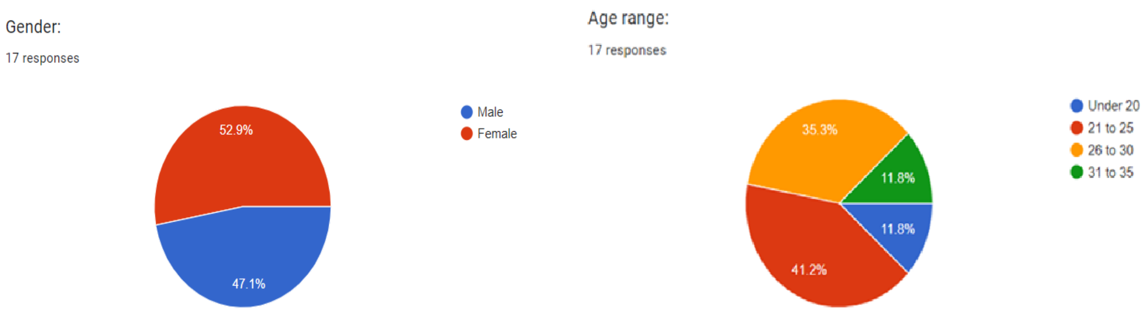


Fig. 15. Demographic data of the interview participants (Gender and age) (Source: Authors).

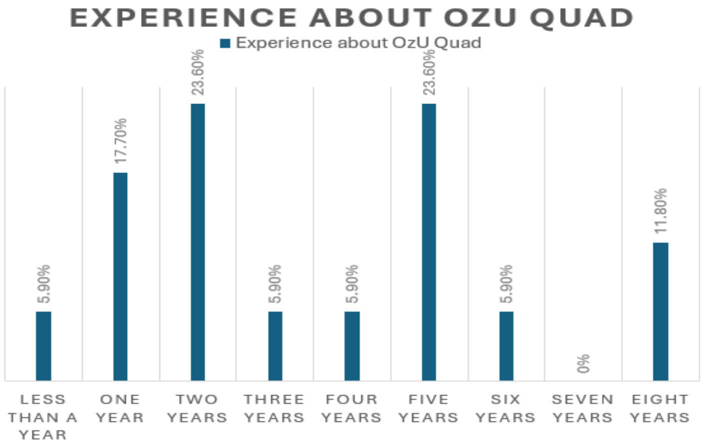


Fig. 16. Experience or duration of stay in Ozyegin University (Source: Authors).

Fig. 16 above is a bar chart about the experience or duration of stay in the University by the participants, those with 2 years and 5 years have 23.6% each, then those with 1 year have 17.7%, followed the 11.8% for 8 years, while 3 years, 4 years, 6 years and those with less than a year have 5.9% each. The participants were also a mix of varied cultural backgrounds available on the campus, consisting of Turkish, Nigerians, Ghanaians, Iranians, Iraqis, Bangladeshi, Jordanians, Mauritians, and others.

The data further reveals three categories of participants: Frequent visitors, Occasional or Rare Visitors, and Non-Visitors. Perception of all is important as it will contribute to answering the research question. According to Bagais (n.d.), people's personal characteristics, experiences, and intentions can have influence on how they perceive and respond to the affordances in their environment. He identifies sub-factors like age, personality, and familiarity with space mediators of affordance perceptions. According to the data, several participants visit the Quad frequently, favoring specific spots for various reasons. For example, some respondents prefer quieter sections, like the area near the Faculty of Architecture and Design or the lower Quad, which is described as more peaceful and less crowded. The area near the Student Center or around Café Nero is popular because it's a central meeting place that allows easy socializing. Some respondents mention the banks near the business building or grassy areas, noting their spaciousness and a more relaxed atmosphere. For occasional users, these respondents tend to pass through the Quad without spending much time there or only visit occasionally. They tend to seek less crowded spots when they visit, preferring quieter corners or shaded areas. A few participants mentioned they like to visit the lower Quad when it's less busy, allowing them to have a coffee or relax without much disturbance. For the non-visitors, a few participants indicated that they don't visit the Quad at all or rarely do so, without providing specific reasons. Some mentioned they feel comfortable anywhere on campus, suggesting that the Quad isn't particularly significant to their campus experience. The majority of the frequent users seem to appreciate and decode the affordances given by the spaces regarding accessibility, sociability, comfort and activities.

5. Discussion

Two recent studies (Şen et al., 2020; Ozbil et al., 2018) related to OzU are both more quantitative in nature because they integrate space syntax analysis with behaviors, which prevents them from being able to look in depth at the variety of behaviors in this area, which makes Ozbil et al. narrow down the behaviors to only two categories (passive and active). Şen et al (2020) focused on the population of users and not mainly on behaviors. Therefore, using affordance theory in this study revealed the presence of variety of affordances and niches (Li, 2013) including the real affordances & perceived affordances (Yilmaz et al., 2017), passive and active (Ozbil et al., 2018), improvised & serendipitous (Stevens et al., 2023), dominant and present (Bechtel, 1989), reflexive, reactive, reflective (Kannengessier & Gero, 2012), hidden and false affordances (Gaver, 1991, as cited in Li, 2013) resulting in different behaviors depending on the location and characteristics of both users and the environment. The characteristics of the environment including aesthetic value (Guo, et al., 2023), space organization (Abu Elkhair et al. 2023; Ozbil et al., 2018) as we have seen, proximity, location and accessibility played a role in making areas such as the front of student centers (Q1) and the central area (Q3) very active and containing the most behaviors due to their proximity to both social, academic and commercial areas. Design elements also contribute significantly to the health, well-being and affordances of urban open public spaces, as Ozbil et al (2018) and Bressane et al (2024) have shown, we have seen how design elements such as integrated walkways, and the number and types of seating or other objects encourage or discourage certain affordances. Natural elements such as grass and water features have also been shown to be beneficial when it comes to environmental affordances as Bressane et al (2024) has shown, similarly during the interviews some of the occasional visitors and non-visitors pointed to absence of natural elements such as water features as being among the things that make them less concerned about using spaces. While frequent users pointed to greenery as one of the objects that attracts them to the place. On the other hand, survey results also showed the relationship between individual/group characteristics (Bangis, nd.) and affordances. Rietveld et al (2013) reported that shared norms, activities, and meanings associated with a space can enable or constrain certain behaviors and interactions. However, some of the non-users could not give a reason for that, a number of them also indicated that many other places on campus could provide them with what the Quad would provide, and some occasional visitors related their usage pattern to the number of people, climatic conditions, or their mental state. Some of the frequent users acknowledged that using the OzU quad when they were under stress helped them in relieving stress, this aligns to the findings of (Bressane et al, 2024; Darma et al, 2023 & Shahmiri et al, 2024) on exposure to green spaces and reduction of stress and alleviation of anxiety and boost productivity. Generally, this indicates challenges of social inclusivity due to the existence of occasional users and non-users among students. Additionally, there are indications of under-utilization and concentration of behaviours, which were also reported as 'overcrowded' by Ozbil et al (2018). It is evident in an imbalance of behaviors and affordances that some parts of the Quad possess, for instance, the difference between the behaviors and affordances observed in front of the student center (Q1) or central quad (Q3) and the lower quad (Q5) or front of the architecture faculty (Q6).

The primary objective of this study is to explore the affordances that OzU quads have on students in schools by looking at their behavior in this environment and the qualities of this environment, which together will allow us to understand the affordances that are encouraging and those that are discouraging. Additionally, this will allow us to identify issues of social inclusion, concentration of behaviors, and underutilization. To foster more inclusive and dynamic public urban spaces, a multifaceted approach is essential. Promoting social inclusion begins with designing for diversity by incorporating flexible seating, shade, interactive and more natural elements that accommodate various user needs across age, culture, and ability. To disperse concentrated behaviors, amenities such as seating and shading should be evenly distributed, and spatial designs should offer a mix of quiet zones, social hubs, and transitional paths. Lastly, under-utilization spaces can be revitalized by enhancing comfort through improved shading, greenery, and ergonomic furniture, activating them with occasional events or art installations, and improving signage to guide users towards these areas, making them feel more inviting and purposeful. Participatory design and occupancy evaluation are also useful things as Ozbil et al (2018) suggest.

This study was conducted within a limited period (5 days of observations) within a specific season of the year -the fall of 2024. Expanding this period to cover the whole year might reveal more seasonal or occasional usage affordances. It is also recommended that conducting studies of this nature relating to affordances should be on a regular basis in outdoor spaces so that they can help to understand the use of the space and identify problems that occur as a result of usage and behavioural change to improve its social capability and efficiency.

6. Conclusion

Affordance theory is a very useful tool for understanding human behavior and how they interact with their environment. This study explored social affordances that encourage behavior in Ozyegin University central square (OzU Quad) to improve its social quality, which is very important for students' social and mental well-being. The findings of this study were based on behavioral observation and mapping, which allows evaluation of social affordances that cause these behaviors. In-depth interviews were also conducted with some of the students to hear their experiences and the influence of the environment on their social well-being. The results concluded that spatial organization, especially the proximity and location of facilities, plays a significant role in creating the environment's affordances. The same applies to objects in the environment, for instance, areas with fewer seats that afford movements and discourage social behaviors such as relaxing and other passive activities. Furthermore, the results showed three basic categories of students which include frequent visitors, occasional visitors, and non-visitors, this is associated with reasons related to overcrowdedness, and the lack of certain natural features such as water bodies, etc. This shows a need to promote social inclusivity and address challenges of concentration of behaviors and under-utilization by providing flexibility in the design and arrangements of objects, and improving signage, shedding, etc. Participatory design is also essential as it will allow users to organize the environment based on their needs. Finally, there is a need for further research, especially considering that this study was conducted within a limited time, thus a need for the future research to cover the entire year, as there may be affordances and additional information due to climatic conditions and some annual social gatherings usage that were not captured during this observation. Additionally, research of this kind that deals with affordances is valuable and should be conducted regularly to better understand the relationship between behavior and the environment in light of how the world is changing, providing opportunities for improving the efficiency of the environment at all times.

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A rock carving structure of Eymir Khan

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Abstract. With the development of trade relations along the Silk Road and other trade routes, caravanserais and khans gained significance. These architectural characteristics were shaped by their periods' social, economic, commercial, and religious contexts. Since pack animals required rest approximately every 30-40 km, lodging facilities were built at these intervals. Caravanserais and khans provided accommodations, baths, stables, and services such as shoemakers, tailors, and dyers for travelers' needs. However, technological advances and the transition to motor vehicles replaced caravans, significantly shortening travel times and shifting trade into urban areas. Consequently, rural lodging facilities lost their purpose and became abandoned.
This study examines Eymir Khan, approximately 40 km from Gercüş in Batman Province, Southeast Anatolia. Constructed uniquely by carving into rocky terrain on a hillside, its exact construction date is unknown. The khan consists of two units: the central section is built from rubble stone adjoining the rock face, and another unit is considered buried underground. The building's condition was documented through site visits, detailed photographs, surveys, and architectural drawings. Its architectural features and preservation issues were identified, and recommendations for future conservation efforts were provided.

Keywords: Rock carving; Khan; Conservation; Construction system; Architectural heritage

1.Introduction

Rock-cut structures are unique in architectural history as physical and cultural expressions of humanity's relationship with nature. These structures emerged through the human manipulation of natural rock masses, designed to serve various purposes such as shelter, worship, defense, and trade. Unlike other construction techniques, rock-cut architecture is characterized by a subtractive approach, wherein rock formations are sculpted by excavation. Thus, it represents rare architectural examples created by removing rather than adding building materials (Pekin, 2014).

Rock-cut architecture has been widely utilized, particularly in regions with easily workable geological structures, such as volcanic tuff. The formation of these structures varies depending on local geological features, climatic conditions, and cultural dynamics (Dincer et al., 2020). This indicates that these structures' architectural forms and functional purposes are significantly influenced by their local context.

The Anatolian geography historically hosted significant trade routes, fostering the development of lodging structures like inns and caravanserais along these routes. These structures were more than temporary accommodation spaces; they became centers of trade, cultural exchange, and social interaction (Kılıçözlü, 1985). Particularly during the Anatolian Seljuk period, numerous caravanserais were built due to the flourishing trade, arranged systematically along important trade routes. Typically, these caravanserais featured a single entrance leading to a central courtyard surrounded by rooms accommodating people and animals (Burlot, 1995). Especially from the 11th century onwards, under Anatolian Seljuk rule, caravanserais evolved into key centers for commerce and social and cultural life (Köprülü, 1942). As cities expanded and trade shifted towards urban centers, inner-city versions of these structures emerged, known as "khan."

Three rock-cut, closed-plan khan structures were identified in a study conducted in the Southeastern Anatolia Region. These include the Eymir Khan in Batman Province, the Konak Khan in Diyarbakir Province, and the Merkez Khan in Mardin Province. When these khans are compared, the Merkez Khan is located in the Savur district of Mardin. Its construction date is unknown. According to information in the Savur Management Plan, it is thought to have been built in the 16th century, although no definite information has been found (SYP, 2016–2021). The structure in Gazi Neighborhood of Savur was constructed using rubble stone masonry. Except for the entrance façade, the remaining façades are attached to adjacent buildings and do not face the street.

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The structure is accessed through a semi-circular arched entrance gate with a non-original iron door. A column supporting the ceiling is located in the unit facing the entrance. This space is covered with a groin vault. The structure's central unit is divided into three naves by nine columns and was constructed using a rock-cut technique. A sealed doorway in this section is believed to have provided access to an adjacent room.

An additional structure was later attached to the original building, and entry to this section is through an iwan leading into rooms. The iwan is also covered with a groin vault. The structure shows significant similarities in plan and construction technique with the Eymir Khan, located approximately 25 km away in Batman.

Another example of a rock-cut khan is the Konak Khan located in Konak village of the Egil district in Diyarbakir. Much of the structure has collapsed in the present day. The construction date is unknown, and the building does not contain an inscription. It is currently used as a stable. The interior can be accessed through an opening on the north-facing entrance façade. The Diyarbakir Cultural and Natural Heritage Preservation Board (DKVKBK) registered the building in 2020. To the west of the entrance is a 2x3 unit, and to the east is a 5x3 unit. On the entrance façade's southern line, another space measuring 3x2 meters. The khan consists of a total of three units, which include rock-carved animal feeding troughs. The spaces are divided by rock-cut columns, and the passages between units feature low arches. Openings in the ceiling, believed to have been created for ventilation and lighting, are also present. This study aims to explore Eymir Khan as an example of rock-cut architecture developed within this historical context, examining its architectural, historical, and functional dimensions. By analyzing its construction technique, materials, and layout, this research will assess Eymir Khan's contributions to rock-cut caravanserai architecture in Anatolia. In this context, Eymir Khan will be thoroughly analyzed in terms of both its architectural characteristics and cultural and historical significance (Kakdas Ates, 2024).

2. Field Study

2.1. Location of Eymir Khan

Eymir Khan is located in the Southeastern Anatolia Region, within the boundaries of Eymir Village, affiliated with the district of Gercüş in Batman Province. Eymir Village is situated approximately 40 kilometers northeast of the Gercüş district center. Official records identify the khan structure as parcel 5, block 109. This information, sourced from the Batman Cultural Inventory published in 2017, classifies the structure as belonging to the Medieval period. One notable aspect of the building is the absence of any inscriptions, complicating the determination of its exact construction date. However, analyses based on architectural characteristics and construction techniques allow for some inferences regarding its historical period.

Eymir Khan distinctly differs from other regional inns in its construction technique. The rock-cut method in its formation enables the structure to blend harmoniously with its natural surroundings, providing an alternative example to local building traditions. Consequently, Eymir Khan surpasses its functional role as accommodation, standing out as a unique architectural exemplar (Fig 1).

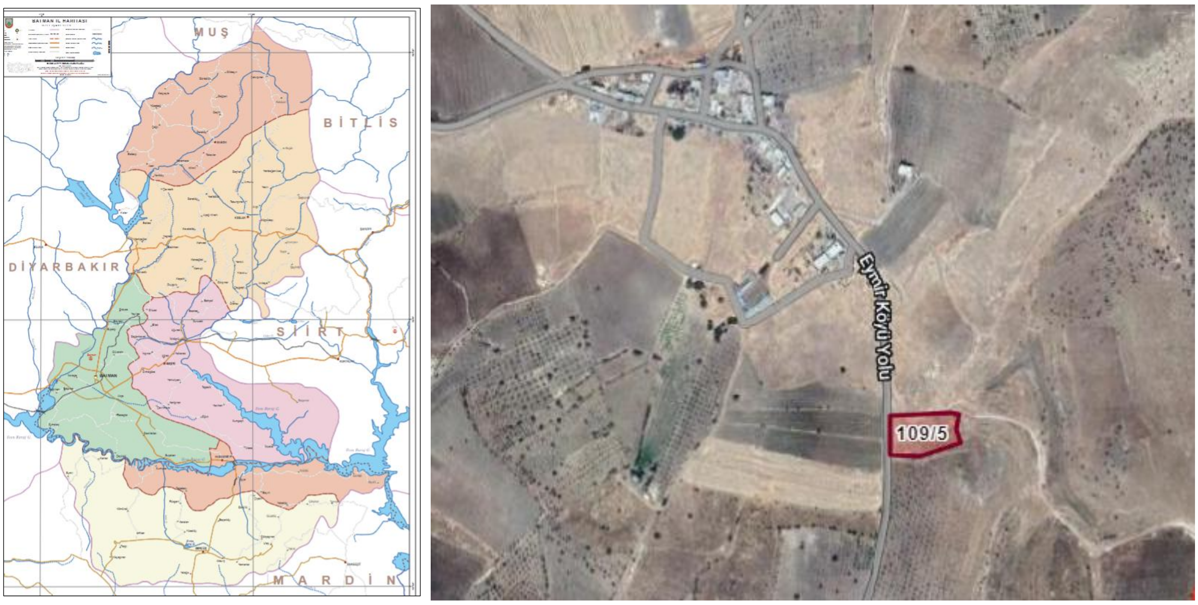

Fig. 1. Batman District Map (HGM, 2025), Location of Eymir Khan (TKGM)

2.2 Architectural Features

Eymir Khan features a simple yet functional layout consisting of two main units. The first unit served as a stable, while the second was designed for accommodating travelers. The section carved into the rocky ground is associated with its function as a stable, a hypothesis supported by on-site examinations. Particularly, the carved feeding troughs found within the space clearly indicate that this area was used for housing animals (Fig 2).

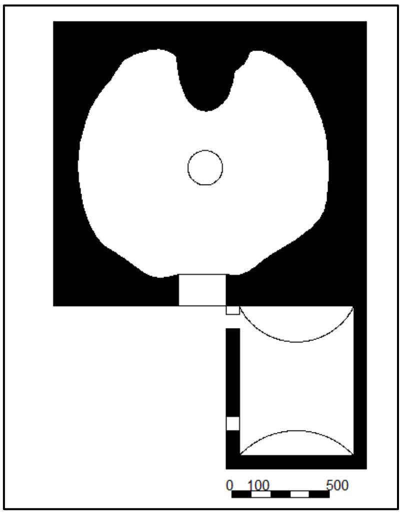

Fig.2. Plan Drawing of Eymir Khan (Author's archive)

Fig. 3. Photograph of Eymir Khan Entrance Door and Traveler Accommodation Unit (Author's archive)

The second unit, identified as the traveler accommodation area, was constructed using a different building technique. This section was built using rubble stone masonry rather than being directly carved into the rock (Fig 3). It features an entrance door and a small window, which provides lighting and ventilation. This window opening not only allows natural light to enter the space but also supports air circulation within the interior (Fig 4).

Fig. 4. Interior Photographs of Eymir Khan (Author's archive)

The coexistence of these two construction techniques indicates that Eymir Khan possesses a hybrid architectural character. While the rock-cut stable section was created by utilizing the natural features of the local geography, the rubble stone accommodation unit may have been added later or represent a different construction preference. This aspect is significant as it provides insights into the possible phases and transformations the structure underwent during its period of use (Fig 5).

Fig. 5. Photograph of Eymir Khan Entrance Facade and Top View (Author's archive)

3. Conclusion

Eymir Khan is an important example of how rock-cut architecture was applied in civil architecture, holding a unique place within Anatolia's historical and cultural heritage. Located in Eymir Village, affiliated with the district of Gercüş, the structure stands out for its integration with the natural environment and its combination of different construction techniques. The rock-cut section is stable, and the rubble stone masonry accommodation unit indicates that the building was designed with functional unity. Although the exact construction date remains unknown due to the absence of an inscription, based on its architectural features and building techniques, it belongs to the Medieval period. Eymir Khan can be regarded not only as a place of accommodation but also as an element that sheds light on its era's economic, social, and cultural structure. The study of the building reveals that it differs from other inns and caravanserais in the region and showcases an architectural approach tailored to local conditions. In this context, Eymir Khan provides important clues about the reflections of the rock-cut building tradition in civil architecture in Anatolia.

The preservation, documentation, and support of the structure through more comprehensive archaeological and architectural research are of great importance for both architectural history and the sustainability of cultural heritage. Future comprehensive studies will contribute to deeper analyses of the region's historic building stock and architectural diversity through examples such as Eymir Khan.

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Analysis of design parameters in office buildings in terms of sustainability concept: The case of Ankara province

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Abstract. Office buildingss are among the pioneering architectural structures in terms of technological integration with significant energy consumption during both construction and operational phases. In addition to their structural features, the relatively high number of users and visitors causes energy consumption and therefore management costs to reach high levels in offices. Designing for lower energy use, integrating on-site energy generation systems, avoiding energy leaks and losses, and creating techniques for reusing otherwise wasted energy are all crucial tactics for achieving sustainability goals. System maintenance, structural improvements, and ongoing office space utilization are also essential for prolonging building lifespans and advancing sustainability goals. This study investigates the strategic operational decisions influencing office building management, how these decisions are reflected in design, and how spatial construction impacts energy conservation and operational costs. The research methodology includes a literature review on the economic dimensions of office sustainability, analysis of case studies, and field evaluations. Findings derived from interviews with office developers and designers in Ankara are compared with insights from the literature to assess alignment with sustainability criteria and identify design strategies that can reduce operational costs.Furthermore, the study proposes energy-saving solutions for office buildings. In the context of facility management of offices, attention was drawn to the spatial use decisions and the effects of the saving installations and systems used in them on energy costs. In this way, it is possible to increase awareness in sustainability studies by explaining the relationship between management cost and design. According to the results of the research, it has been revealed that significant energy savings are achieved with the rational use of design decisions taken in terms of energy use, this reduces the cost of management, and in this respect, sustainability can be achieved in terms of the use of office buildings, and also in terms of energy conservation, this situation serves sustainability due to its environmental effects. The research concludes with spatial solution proposals that enhance sustainability in office projects and outlines the advantages of sustainable design principles for both developers and designers.

Keywords: Office buildings; design parameters; management costs; energy use; sustainability

1. Introduction

The tendency to consolidate workspaces in public and private institutions necessitates the gathering of office workers from different walks of life and increasing accessibility. Offices are generally used in public areas with the increasing population mobility and urbanization effect. Office buildings, which are generally located in the city center; When evaluated in terms of aspects such as the line of work carried out, its capacity, the number of users and visitors, there are structures with high frequency of use (Demirkaya 2024). In particular, the high number of users triggers the energy consumption arising from the activities carried out, which also affects the operating cost and directly affects the return or profitability of the investment (Tanrıvermis & Tanrıvermis 2021).

Due to the fact that office buildings are large-scale investments, the measures that can be taken in terms of initial investment cost and usage opportunities have a significant impact on investment profitability. Strategic decisions and applications taken into account during the design phase are important in terms of the structural features of the building such as selected materials, installed systems, space organization, and the way the spaces are used. When this situation is evaluated, there is a need to determine the strategic design parameters that should be taken into account in investment decisions. In this study; By using the results of the resource research together with the in-depth interviews and cash results with investors, project developers and designers, the disadvantages

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of existing office buildings were examined and it was possible to determine the issues that should be taken into account in new office projects to be built in the coming years. The results of the study are expected to be a guide for real estate developers, designers and investors.

2. Materials and methods

In the study, future design criteria and current usage characteristics for office buildings both in general and in Ankara were evaluated. In the study, data were collected by conducting in-depth interviews with office developers/investors and office designers. In this context, 10 people were reached as investors and 30 people as designers. It is considered that investors and designers, as important decision-makers in terms of design criteria and spatial expectations, play an important role in shaping the buildings, and that the building can provide significant energy conservation during the operation or usage period with the decisions to be taken in terms of sustainability and energy conservation.

Within the scope of the research conducted for offices with professional facility management located within the borders of Ankara province and offices managed at the independent department level and with traditional usage styles, opinions and data on both groups were reached. Care was taken to collect data for office buildings with different use, design and management features, and the findings were mutually examined. Since the office typologies that office users can prefer are predominantly in these two groups and each typology has its own usage characteristics and potentials, it is aimed to reach the data for the groups determined in the study. By evaluating the obtained data with a focus on facility management and sustainability, it is aimed to reach the basic design parameters for new projects and office investments that can be developed and designed in the coming years.

3. Literature

3.1 Research on building materials, population, and construction processes

Life cycle processes of a product; raw material acquisition, production of equipment, production of the product, packaging and distribution of the product, application of the product to the structure, use, maintenance and repair of the product, repetition of use, recycling or destruction of the product with the completion of its useful life (Tuna & Taygun 2011). Similarly, facility and building management starts with the birth of the project idea and covers many processes such as planning, feasibility studies, construction and construction process, use phase, demolition phase. The characteristics of each of these stages differ, but when their effects on each other are evaluated, they should be considered as a whole.

The production and use phases of building systems are defined by Gültekin (2006) as the extraction phase of the raw material, the production phase, the construction phase, the use phase, the demolition phase and the post-demolition phase (Fig. 1). In the use and production stages of the buildings, it is necessary to provide the needed energy, materials and resources. In these processes, which include highly dynamic and complex processes, all stages must be designed in a holistic manner in order to ensure the use of the buildings in a sustainable manner and a well-thought-out facility management strategy must be implemented in order to provide the necessary services to the users without interruption.

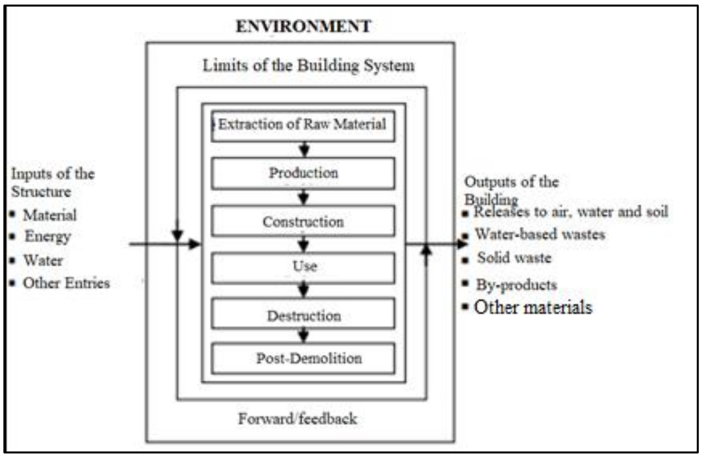

Fig. 1. Building system diagram (Gültekin, 2006)

Although the factors of facility management vary considerably, one of the most important issues is the construction of the systems, the organization of the space and the selection of the building materials that make up the space. At this stage, all factors and usage scenarios that may be encountered regarding the structures should be discussed in detail. On the other hand, the compatibility of the systems with each other, the level of exposure to external stimuli and the similar conditions of the technical benefits they provide have an impact on the economic life of the buildings.

The variety of uses and usage possibilities of building materials have been directly related to the proximity to raw materials for the traditional building production period. Issues such as the supply of raw materials, their use as building materials, transportation and processing have led to the emergence of construction styles according to the region and have been effective in the choice of use of materials. Building production has changed over the years, the way the materials used are brought together has changed due to aesthetic concerns in some cases, functional needs and technology used in some cases, and an improvement has been tried to be achieved in the production of building materials. With the development of technology, factors such as the diversification of the tools used in construction and the production of intermediate structural elements extended to the production of new building materials with the Industrial Period. It has been possible to transfer building materials and structures produced in a prefabricated style, and in addition to intercity and international transportation opportunities, construction technologies have evolved to robotic production technologies under current conditions (Fig. 2).

Paleolithic Age	Paleolithic Age Mesolithic Age	Mesolithic Age Nesolithic Age	Mesolithic Age Nesolithic Age	Nesolithic Age Burning Fire Efficiently	Nesolithic Age								First Experimental Study on Materials	Industrial Revolution Cement First Study	Industrial Revolution Bessemer Method	World Wars	
B.C.													A.C.				
2,5 millions	120. c.	90. c.	75. c.	70. c.	55. c.	50. c.	33. c.	27. c.	25. c.	4. c.	3. c.	0	17. c.	18. c.	19. c.	20. c.	21. c.
Natural stone Natural wood	Clay	Mud+ Stone wall	Adobe			Copper	Bronze	Steel	Glass	Brick Tile	Rome Concrete	Khorasan mortar		Font, Wrought iron	Portland cement Plastics Reinforced concrete Glass Aluminum, Titanium	Polymers Composites	Nano materials

Fig. 2. The main properties of materials (Çorbacı, 2015)

With the increasing technology in structural production, it is clear that the energy requirement used in production is at a low level with less processing costs and there is a need for structural production with materials that can be found in the conditions of the production geography. On the other hand, it is noteworthy that the degradation and maintenance needs of the materials in its geography are at a lower level than other structural systems and the cost of use is low. It is noteworthy that materials that move away from naturalness with chemical and mechanical processing have negative effects on human health if they are used as building materials.

Air conditioning, which is provided by active and passive solar systems, which is one of the environmentally compatible building design criteria, is suitable for human health due to its naturalness, as well as reducing harmful effects on the environment. It is also understood by traditional architectural examples that solutions provided by natural methods are healthier. If the materials used in a building are produced or sufficient in the region where the building is located, they are healthier in functioning and creating internal climates as natural building materials determined by the climate of that region (Bozdoğan, 2003). In the past, 30-40% organic materials such as wood, straw and reed and 60-70% inorganic materials such as adobe, stone, tile and lime were used in buildings, but today 90-100% artificial materials are used and healthy spaces cannot be created in terms of environment and people (Akman, 1999).

It is noteworthy that the world population has increased more than 4 times in the last century, and under current conditions, the world population is 8 billion people (Anonymous, 2025). The fact that this increase was only 2 times in the previous century reveals the importance of the issue. The increase in the need for the built environment also reveals the need for an increase in the artificial environment with the technological developments. It should be noted that with the increase in the world population, there is a need to increase the presence of the built environment such as housing, workplaces, and social centers (Fig. 3).

It is noteworthy that in the face of the increasing population, the production rate has increased in order to meet basic needs such as food, accommodation and creating a living space. It should also be noted that the concept of sustainable emerged in this way. Meeting the housing and structural needs of the growing population is also seen as a necessity, as well as the consumption of natural resources is intense.

With the increase in the population, it is expected that there will be an increase in the number of built spaces used and the total usage area. This increase is realized both at the level of the built area per capita and with the diversification of collective living spaces that emerge with the increasing population. It is an issue that attracts attention in urban living spaces where the need for indoor space that people need increases with increasing technology. For example, although the areas where the need for sports is met in rural areas are places such as open fields, fields or roads that are not frequently used by vehicles, there is a use of areas where structural production is needed, such as landscaping and indoor sports centers, in urban living conditions. When evaluated in terms of residences, relatively small-scale buildings are produced in rural areas, while there are more intensive uses in urban living areas, as well as the presence of many gathering places such as bus terminals, cinema and theater halls, museums, recreation areas, work centers, offices, factories, logistics and storage units and public transportation centers as the meeting point of the masses, is similarly effective in increasing the amount of buildings. It should be noted that this situation is related to the use of technology and the increase in the needs arising in urban development.

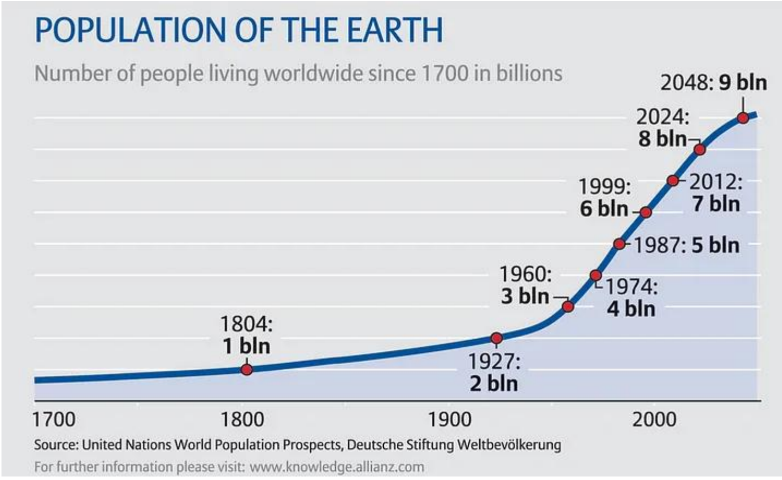

Fig. 3. The growth trend of the world's population (Anonymous, 2025)

With the increase in population presence and the diversification of usage needs in building production, there is a significant differentiation in the building materials needed for the use of space. The consumption of cement as a building material brought to the building sector by the Industrial Age has been compared with the population growth, and the increase in the amount of consumption, which has almost doubled in the last ten years, is almost equal to the increase in the period of about seventy years until ten years ago. This situation is an important proof that there is a lot of weakness in ensuring sustainability in building production. So much so that it is known that as a structural binder that cannot be easily reused, the damage caused by cement to the environment during the production phase is at a very high level.

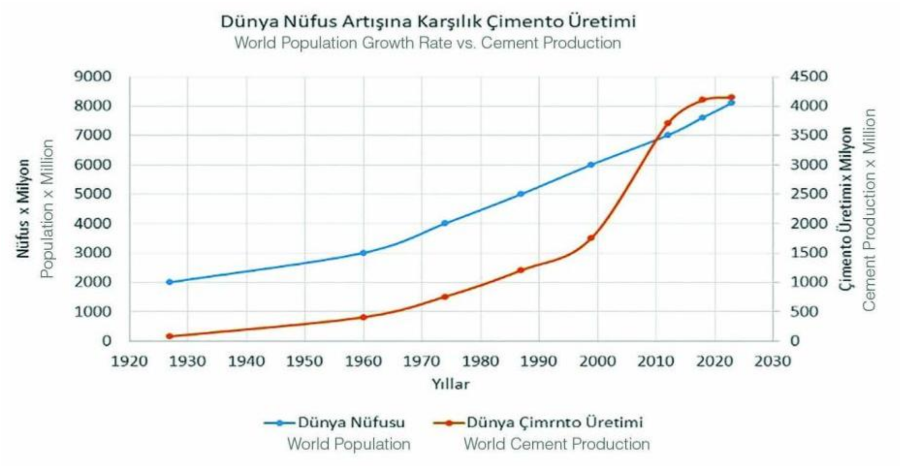

Fig. 4. The relationship between world population and cement production (Anonymous, 2024)

Heat island effect; It is the increase in the temperature in the city center by 2-3 °C during the day compared to the rural area by means of the solar heat stored on the roof and walls of the building. Increasing temperature is the cause of global warming (Oren 2010). Heat islands that emerge as a result of urban construction have an effect on the climate structure and regionally increasing temperature generally has negative effects on comfort conditions. This situation necessitates the control of the ambient temperature, and therefore energy consumption varies according to geographical regions and seasonal effects for this control.

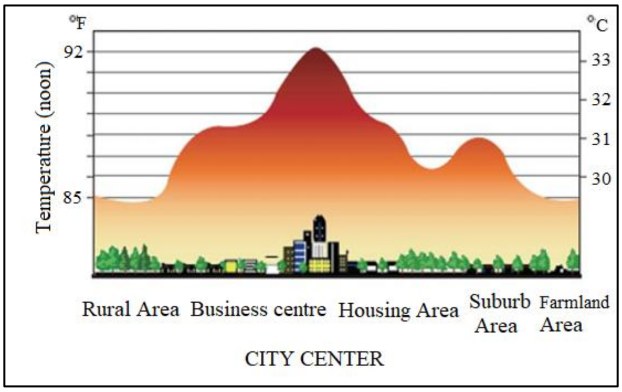

Fig. 5. Temperature changes in different regions with the heat island effect (Ören, 2010)

1.2. Examining energy use in offices
In the study conducted by Yalılı Kılıç & Yahşi (2019), the amount of energy consumption between classical office use and green office use was compared. In the comparison made regarding the use of electricity, natural gas and water, it was evaluated that the use of green offices was relatively less. This is considered as clear evidence of the contribution to the operating cost.

Table 1. Comparison of the use of electricity, heating and cooling systems of classical and green offices (Yalılı Kılıç & Yahşi 2019)

Product	Usage Amount - Classic Office	Usage Amount - Green Office	Savings Made (%)
Electricity	17,071.51 kWh/yıl	6,566.16 kWh/yıl	61.54
Natural gas	6,574 m^3/yıl	1,622.4 m^3/yıl	75.32
Water	833.28 m^3/yıl	275.52 m^3/yıl	66.94

In the examination of energy consumption for office buildings, energy consumption rates arising from heating, cooling, lighting, use of pumps, fans and machine use were examined. According to the results of the study, it was evaluated that the highest energy consumption was realized for lighting with 38%, heating with 24% and cooling with 19%.

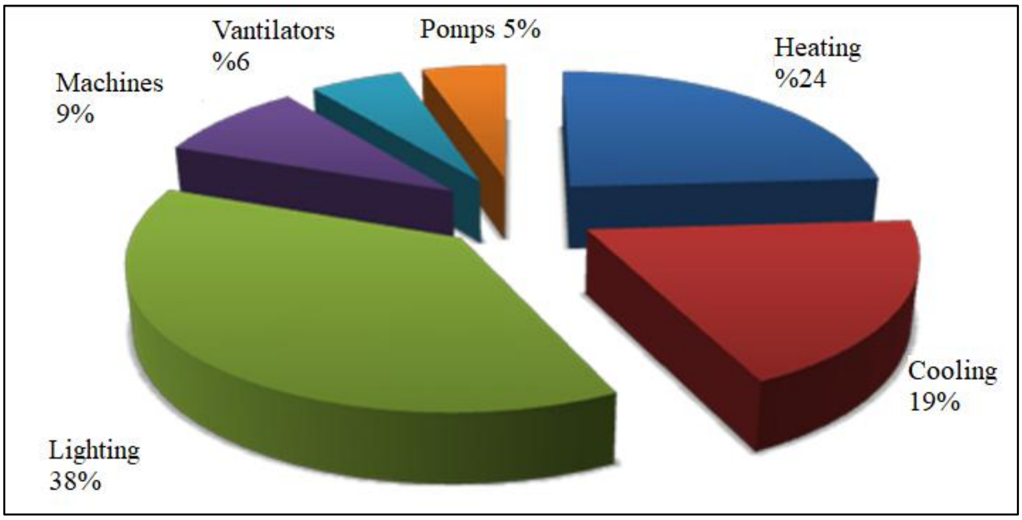

Fig. 6: Shares of energy consumption groups in total energy consumption (Ören, 2010)

In the study conducted by Ören (2010), the effect of daylight consumption on energy consumption was examined and the change in the amount of energy consumed for heating, cooling and lighting actions was simulated through the same structure. According to the results obtained, the total energy use rate of heating decreased by 27.5% for lighting and decreased by 12.5% for cooling processes, while the share of heating in total consumption increased by 12.8% (Figure 7).

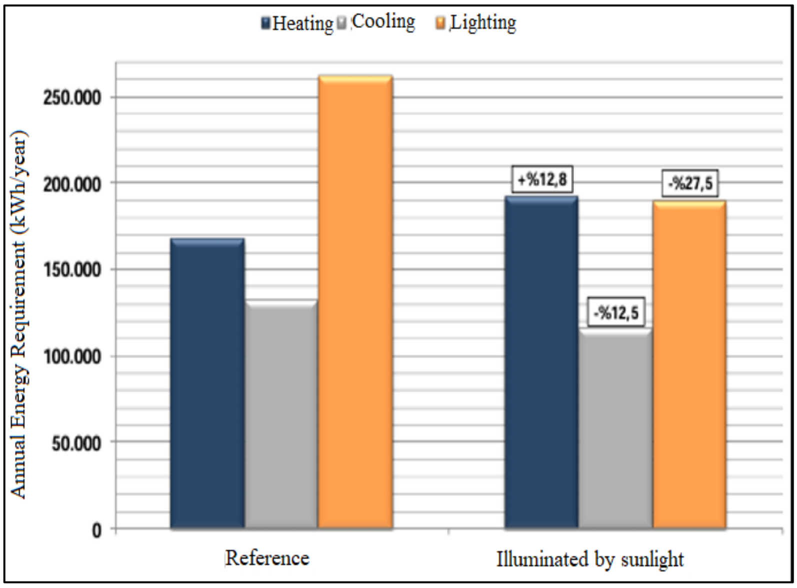

Fig. 7. Impact of daylight lighting on energy needs for reference building (Ören, 2010)

The amount of energy use needed for offices differs according to the units, the time spent in the units and the frequency, duration and form of use of the spaces. The spatial setup strategy is provided correctly and the needs-oriented design of the systems in the spaces have an impact on the amount of energy consumption. The amount of savings achieved through rational analysis is also reflected in the operating cost, which has an impact on the level of profitability for investments. In the study conducted by Erkin (2012), according to the simulation results of energy performance and saving calculations, the results of energy saving and lighting control and lighting energy performance and saving calculations for the office building with a total usage area of 12,170 m^2 were revealed. Accordingly, while 53.6% savings can be achieved with the energy saving model, 68.4% energy savings are achieved with lighting control (Table 2).

Table 2. Analysis of use according to energy control alternatives (Erkin, 2012)

Indicators	Current Status	Energy Saving	Lighting Control
Parasitic Power (W)	0	0	5.153
Parasitic Energy (kWh)	0	0	45.138
Lighting Installed Power (W)	240.959	107.180	107.180
Lighting Installed Power (W)	505.407	225.891	113.889
Total Electrical Energy (kWh/year)	505.407	225.891	159.026
AESG (kWh/m^2.year)	41,5	18,6	13,1
Energy Saving (kWh/year)	-	271.069	345.536
Energy Saving Rate (%)	-	53,6	68,4
AETG (kWh/m^2 year)	-	22,3	28,4
Investment Cost [TL]	-	205.860	358.530
Payback Period (years)	-	2,9	3,9
AETEG	-	1,32	0,96

The level of energy use in buildings varies depending on many variables such as the functions of the buildings, the intensity of use, the type of structural system and filling material, the location of the buildings and the selected mechanical and electrical installations. According to the data of the American Department of Energy (Anonymous, 2009), it is noteworthy that energy use differs at the level of installations used within the buildings as well as the building function.

Table 3. Total energy use distribution according to the functions of buildings (Anonymous, 2009)

Type of Consumption	Housing (%)	Office (%)	School (%)	Hospital (%)
Heating	43.1	35.3	47.4	37.5
Cooling	10.2	9.6	9.6	7.5
Lighting	5.9	24.9	13.8	17.6
Hot water	20.4	2.2	7.0	16.1
Other equipment	9.4	9.4	4.6	2.5

It is considered that the possibility of lighting is an important cause of energy consumption for office buildings. In particular, the right and desired light is needed for working environments, and in order to work in a concentrated manner, it is necessary to provide homogeneous lighting and therefore lighting control must be carried out. In the study conducted by Onaygil et al. (2005), energy consumption for lighting purposes and the share of lighting in total consumption were analyzed for office buildings with different sizes and usage possibilities. It was understood that the total energy consumption share and the amount and share of energy consumption for lighting purposes varied according to the characteristics of each building, and the share of energy used for lighting in the total for the buildings examined was in the range of 10.0-27.1% (Table 4).

Table 4. Energy use data of different buildings used as offices (Onaygil et al. 2005)

Building number	Construction area (m^2)	Lighting Power (W)	Annual lighting consumption (kWh/year)	Share of lighting (%)
Office-1	9.924	121.858	275.529	21,2
Office-2	12.997	145.523	341.425	23,9
Office-3	10.200	122.100	997.764	16,7
Office-4	18.000	260.239	654.409	21,0
Office-5	17.022	181.483	605.420	10,0
Office-6	35.295	255.525	710.518	13,1
Office-7	25.000	244.071	779.592	27,1

According to the results of the research, it has been evaluated that the comfort conditions of the users are suitable if the appropriate air temperature in the office environment is 21-22 0C and the humidity is in the range of 40-65%. In addition, if human movements, mechanical movements and structural elements such as doors and windows are open, it is inevitable to have air mobility in the working environment. For this reason, it should be noted that the speed of air movement, especially within the scope of ventilation of the environment, can be effective in distracting the attention of the employees. It should be noted that the optimal level of air movement for office workers may be appropriate if it is 0.10-0.15 m/s (Karaoğlu 2014). In order to provide the office comfort conditions within the specified scope, it will be necessary to operate the automation systems according to the comfort condition range, and therefore to use energy continuously in cases where the environmental variables are intense. However, if a sustainability-oriented design is made in the context of smart building and smart environment design criteria, it will be possible to provide comfort conditions with passive methods. In this respect, it is necessary to consider not only the building used, but also the climatic conditions, the building environment and the characteristics of the building biology.

It is known that the amount of energy used varies according to the working units. It is necessary to carry out special studies for each structure in order to construct energy management for offices. The plan system and spatial organizations of the buildings vary, and the analysis of each building in terms of energy performance should be provided, the energy performances of the spaces should be taken into account while designing the design and material selections should be provided accordingly. In the study conducted by Erkin (2012), space groups in office buildings; It is classified as working volumes that require attention, detailed work, visual comfort conditions are at the forefront, volumes that are not included in the working volumes, which are mostly for circulation, waiting or resting purposes or that require rough work, volumes where hygiene conditions are at the forefront, and technical volumes. It is important to analyze the factors affecting the design in terms of energy use in terms of energy use as well as the size, purpose and duration, frequency of use, capacity, materials used, exposure to external factors, building envelope properties in terms of working units, technical units, auxiliary spaces.

2. Results and discussion

In the study, data were collected in terms of facility management by referring to the opinions, suggestions and recommendations of the groups interviewed in depth. Data were collected from experts in their fields due to the experience of the developer and designer groups in the sector, their professional knowledge and their decision-making in practice. In this context, meetings were held with a group of 10 developers and a group of 30 designers, and the interviews were held for traditional offices and modern offices.

In the study, the expectations for office investments and offices in Ankara were questioned and the characteristics of the office buildings to be produced in Ankara in the future were revealed. It is possible to adapt the study according to different project characteristics and it is aimed to be a guide for decision makers. In addition, in the light of the current expectations for the office market, the importance levels of sustainability-related issues have been revealed. This situation has been mutually examined and discussed in terms of developers and designers.

2.1 Findings for developers

Office developers have a significant impact on designs, often due to the decisions they make, their role as the final decision-maker, and their entrepreneurial role that requires them to be active in project development, production, and marketing. Especially since they are experts who construct the financial structure of their investments, their views on design are important.

They were asked whether there was a need for production from new office buildings in Ankara and the majority of the participants evaluated that there was a need for the production of new office buildings in the province. 90% of the participants expressed a positive opinion to the question asked. This situation was considered as an indication that work could be done on new office buildings in Ankara.

Table 5. Production need for new office buildings in Ankara

Answers	Professional Office Building		Individual Office		Total	
	Number (n)	Rate (%)	Number (n)	Rate (%)	Number (n)	Rate (%)
Yes	7	87.5	2	100	9	90
No	1	12.5	-	-	1	10.0
Total	8	100	2	100	10	100

The participants were asked about their opinions on the features that the offices that could be produced in Ankara should have, and in this way, the design parameters for the new offices that would be required in the province were also examined. According to the results obtained, the most important services needed are that they have technical infrastructure, parking and valet services, social facilities, security elements and can be divided for flexible spatial use of offices when necessary. In addition to expressing the opinion of 90% of the participants on technical infrastructure services, the expectation of 60% of the participants for office investments with parking and valet services and social facilities should be taken into account for new designs.

Table 6. Production needs and features of new office buildings in Ankara

Properties	Professional Office Building		Individual Office		Total	
	Number (n)	Rate (%)	Number (n)	Rate (%)	Number (n)	Rate (%)
Social facilities	5	62.5	1	50.0	6	60.0
Technical infrastructure	7	87.5	2	100.0	9	90.0
Meets efficiency criteria	3	37.5	-	-	3	30.0
Divisible	4	50.0	1	50.0	5	50.0
Security	4	50.0	1	50.0	5	50.0
Hybrid tenant structure	2	25.0	-	-	2	20.0
Sole proprietorship	1	12.5	-	-	1	10.0
Professional management structure	3	37.5	-	-	3	30.0
Parking and valet services	4	50.0	2	100.0	6	60.0
Healthcare	1	12.5	-	-	1	10.0
Restaurant/cafe	3	37.5	-	-	3	30.0
Meet-and-greet services	2	25.0	-	-	2	20.0
Accomodation service	-	-	-	-	-	-
Green building	1	12.5	-	-	1	10.0
Alternative/flexible use	1	12.5	-	-	1	10.0
Possibility of sports and entertainment areas	1	12.5	-	-	1	10.0

When the participants were asked about the green building characteristics of the office spaces and their willingness to work in the green building, all of the participants expressed their opinion about the willingness to work in the green building. The main reason for this situation is that the developers have knowledge about green building practices and green buildings provide significant advantages in terms of operating costs.

Table 7. Willingness to make the office spaces currently working green buildings

Answers	Professional Office Building		Individual Office		Total	
	Number (n)	Rate (%)	Number (n)	Rate (%)	Number (n)	Rate (%)
Yes	8	100.0	2	100.0	10	100.0
No	-	-	-	-	-	-
Total	8	100.0	2	100.0	10	100.0

The fact that the features and investment strategies for the design of the offices have an impact on the total energy use plays an important role in determining the design criteria and expectations. Investment decisions are effective for developers in terms of project profitability, sales and marketing opportunities. In cases where the right strategies are designed and the spatial features are compatible with the purpose of use, the investment success increases and this leads to the use of sustainable buildings. Operating costs are effective in making the right decisions for use, and this situation reveals the importance of integrating traditional design criteria into the project. It should be taken into account that factors such as usage capacity, functionality, space and material harmony in office buildings are the parameters that significantly guide the design. On the other hand, the fact that the decisions taken during the design phase are effective for the activities to be carried out during the use of the buildings requires detailed research on the decisions taken during the design process.

When the developers were asked about the priority issues for office investments, they were asked about their opinions on sustainable building design, energy efficiency, cost reduction and economy, functional buildings and compatibility of the space program. The most important feature that the developers consider important is that the structure is functional and economical in terms of cost and use. However, it has been evaluated that there is awareness of sustainable building design, energy efficiency and work-space harmony.

Table 8. Issues to be prioritized in the design of office buildings

Properties	Severity	Professional Office Building		Individual Office		Total	
		Number (n)	Rate (%)	Number (n)	Rate (%)	Number (n)	Rate (%)
Sustainable building design	Strongly disagree	-	-	-	-	-	-
	Disagree	-	-	-	-	-	-
	Neutral	3	37.5	2	100.0	5	50.0
	Agree	4	0.0	-	-	4	40.0
	Strongly agree	1	0.0	-	-	1	10.0
Energy efficiency	Strongly disagree	-	-	-	-	-	-
	Disagree	1	12.5	1	50.0	2	20.0
	Neutral	2	25.0	1	50.0	3	30.0
	Agree	3	37.5	-	-	3	30.0
	Strongly agree	2	25.0	-	-	2	20.0
Cost/Economy	Strongly disagree	-	-	-	-	-	-
	Disagree	-	-	1	50.0	1	10.0
	Neutral	1	12.5	1	50.0	2	20.0
	Agree	2	25.0	-	-	2	20.0
	Strongly agree	5	62.5	-	-	5	50.0
Function	Strongly disagree	-	-	-	-	-	-
	Disagree	-	-	-	-	-	-
	Neutral	1	12.5	2	100.0	3	30.0
	Agree	1	12.5	-	-	1	10.0
	Strongly agree	6	75.0	-	-	6	60.0
Work and venue program	Strongly disagree	-	-	-	-	-	-
	Disagree	1	12.5	-	-	1	10.0
	Neutral	2	25.0	2	100.0	4	40.0
	Agree	4	50.0	-	-	4	40.0
	Strongly agree	1	12.5	-	-	1	10.0

2.2 Findings for designers

Designers are important decision-makers in matters such as shaping offices, ensuring their spatial organization, choosing building materials, and designing building systems. Generally, they come to the fore as experts and professionals who are primarily effective in making decisions regarding the level of influence of structures in many ways through teamwork. For this reason, in the in-depth interviews with the designers, their evaluations of office design were questioned and the results were revealed.

When the designers were asked about the production needs of new office buildings in Ankara, it was determined that the participants generally stated that there was no need for a new office building. However, considering the proportion of designers (40%) who stated that there was a need for production for new office buildings, it was evaluated that the features and expectations for new office buildings should be questioned.

Table 9. Production need for new office buildings in Ankara

Answers	Professional Office Building		Individual Office		Total	
	Number (n)	Rate (%)	Number (n)	Rate (%)	Number (n)	Rate (%)
Yes	7	50.0	5	31.3	12	40.0
No	7	50.0	11	68.8	18	60.0
Total	14	100.0	16	100.0	30	100.0

When office designers were asked about the production characteristics of the new office buildings that should be produced in Ankara, it was evaluated that the most important features were the need for offices with technical infrastructure (93.3%), social facilities (63.3%), the ability to divide spaces when necessary (43.3%) and parking and valet services (43.3%). It has been determined that the specified features are generally related to the services that provide convenience in terms of the functionality and usage possibilities of the buildings.

Table 10. Production needs and features of new office buildings in Ankara

Properties	Professional Office Building		Individual Office		Total	
	Number (n)	Rate (%)	Number (n)	Rate (%)	Number (n)	Rate (%)
Social facilities	8	57.1	11	68.8	19	63.3
Technical infrastructure	14	100.0	14	87.5	28	93.3
Meets efficiency criteria	7	50.0	8	50.0	15	50.0
Divisible	5	35.7	8	50.0	13	43.3
Security	4	28.6	5	31.3	9	30.0
Hybrid tenant structure	5	35.7	3	18.8	8	26.7
Sole proprietorship	4	28.6	1	6.3	5	16.7
Professional management structure	2	14.3	2	12.5	4	13.3
Parking and valet services	5	35.7	8	50.0	13	43.3
Healthcare	3	21.4	4	25.0	7	23.3
Restaurant/cafe	7	50.0	3	18.8	10	33.3
Meet-and-greet services	5	35.7	4	25.0	9	30.0
Accomodation service	-	-	1	6.3	1	3.3
Green building	2	14.3	6	37.5	8	26.7
Alternative/flexible use	3	21.4	4	25.0	7	23.3
Possibility of sports and entertainment areas	4	28.6	5	31.3	9	30.0

When the designers were asked about their opinions on the green building of the office spaces they are currently working on, it was noted that the answers of the participants were positive (90.0%). This situation is considered as an indicator of the sensitivity and willingness to use energy in buildings and sustainable building design. As emphasized by Tanrıvermis (2019) and Tanrıvermis and Tanrıvermis (2021), although the investment costs of green offices are relatively higher than traditional buildings, the return on investments is relatively shorter because the operating expenses are lower than traditional buildings.

The opinions of the designers are important in terms of shaping the buildings, constructing the organization of the space, establishing the relationship between the features brought by the size and capacities of the spaces with the structural elements. In particular, designers' analysis strategies and predictions for spatial needs are effective on the creation and functionality of scenarios in the use of buildings. The construction of spatial features has an impact on the activities to be carried out within the building, and this situation also affects strategic decisions in terms of the management of the buildings. There is a close relationship between management activities and spatial use characteristics. This relationship affects the use of office spaces and therefore the cost of use.

Table 11. Willingness to make the office spaces currently working green buildings

Answers	Professional Office Building		Individual Office		Total	
	Number (n)	Rate (%)	Number (n)	Rate (%)	Number (n)	Rate (%)
Yes	13	92.9	14	87.5	27	90.0
No	1	7.1	2	12.5	3	10.0
Total	14	100.0	16	100.0	30	100.0

It was understood that the most important issues were that the most important issues were functionality (100%), work and space program (96.7%) and economical (100%) in terms of construction and usage cost (100%) when the designers were given priority when designing for offices. Although sustainable building design and energy efficiency are secondary priority issues for designers, it should be stated that significant levels of opinion are expressed in this direction (Table 12).

Table 12. Priority issues in the design of office buildings

Properties	Importance Level	Professional Office Building		Individual Office		Total	
		Number (n)	Rate (%)	Number (n)	Rate (%)	Number (n)	Rate (%)
Sustainable building design	Strongly disagree	-	-	1	6.3	1	3.3
	Disagree	2	14.3	-	-	2	6.7
	Neutral	3	21.4	1	6.3	4	13.3
	Agree	6	42.9	7	43.8	13	43.3
	Strongly agree	3	21.4	7	43.8	10	33.3
Energy efficiency	Strongly disagree	-	-	-	-	-	-
	Disagree	1	7.1	-	-	1	3.3
	Neutral	5	35.7	4	25.0	9	30.0
	Agree	5	35.7	7	43.8	12	40.0
	Strongly agree	3	21.4	5	31.3	8	26.7
Cost/Economy	Strongly disagree	-	-	-	-	-	-
	Disagree	-	-	-	-	-	-
	Neutral	-	-	-	-	-	-
	Agree	9	64.3	6	37.5	15	50.0
	Strongly agree	5	35.7	10	62.5	15	50.0
Function	Strongly disagree	-	-	-	-	-	-
	Disagree	-	-	-	-	-	-
	Neutral	-	-	-	-	-	-
	Agree	5	35.7	7	43.8	12	40.0
	Strongly agree	9	64.3	9	56.3	18	60.0
Work and venue program	Strongly disagree	-	-	-	-	-	-
	Disagree	-	-	-	-	-	-
	Neutral	1	7.1	-	-	1	3.3
	Agree	5	35.7	9	56.3	14	46.7
	Strongly agree	8	57.1	7	43.8	15	50.0

2.3 Comparison of findings and discussion

Office buildings are known as the type of building that should be emphasized for urban development due to their impact on their environment, their location in the city and their important investment tools. Due to the technologies they contain, they are also buildings that play a leading role in the building sector, and their spatial setups are generally developed according to certain assumptions. In this respect, structural concepts emerge, some structures are designed and built with a focus on comfort, some with a focus on prestige, technology, energy use or saving.

In the study, in order to evaluate the current situation of the offices and to evaluate the expectations for the offices that are designed in the future, interviews were held with office developers and office designers who are experts in office design and who are decision-makers, and it was tried to determine the features that the offices to be produced in the future should have.

Developers and designers were questioned about the need for office investments in Ankara, the features that offices should have, and the issues prioritized in office design. Issues that can provide sustainable use for office design are examined. It should be emphasized that developers and designers for office designs note similar features. The most important features that should carry their new offices are the functionality, which is the common view for both groups, and the advantages of the buildings in terms of cost and economic aspects. In addition, it was noteworthy that both groups responded positively to the green building characteristics of the existing offices.

When asked about their evaluations of office investment in Ankara, it was noteworthy that developers and designers responded at different levels. While developers state that new office investments are needed, the limited level (40%) of the designers' participation in this view should be perceived as an indication that comprehensive feasibility studies should be carried out for new investments. On the other hand, when asked about the features that office investments should have, it was determined that both the designer and the developer group needed offices that provide technical infrastructure, social facilities, parking and valet services, and whose spaces can be divided or expanded if needed.

In the research conducted on the scale of Ankara province, the current office investment needs and the features that the offices should have were evaluated, and the basic features that should be carried for new investments were determined. However, it is necessary to conduct detailed research on these features and to conduct comprehensive feasibility studies for marketing opportunities, usage possibilities and investment effects.

3. Conclusion and evaluation

Offices are seen as important real estate assets considering their features such as usage intensity, capacity, duration of use, number of employees and visitors. Considering their usage patterns and locations, they generally direct other real estate investments as projects located in the city center and creating attraction areas. The technology and construction techniques used in offices are often pioneering for other projects. Considering the usage densities and capacities, it is known that significant energy use occurs in offices. In addition, construction features that require advanced technology in terms of construction techniques generally require intensive energy use during the construction phase.

It is noteworthy that investment decisions are made during the project development, design and construction stages in the offices, taking into account the initial investment costs. However, when the total building life is taken into account, it becomes clear that the activities carried out during the use phase and the structural systems used are much more important than energy use and sustainability. Therefore, it is now a necessity to take into account the possibilities of use while making investment decisions and spatial arrangements for offices, and to focus on the sustainability goals of the design parameters and the environmental, social and governance analyses of the investments.

In the study, office design parameters were examined in terms of office developers and designers as two important stakeholders that are effective in ensuring spatial organization for office investments and deciding on design elements. In this context, research was conducted on the offices in Ankara, an in-depth interview was conducted with a developer group of ten people and a designer group of thirty people, and the data obtained were examined in terms of office use and project development and design parameters serving sustainability. Project development and design parameters that should be taken into account for future office investments in Ankara have been revealed. In particular, the relationship between office worker satisfaction and business success and preferability will play a key role in new investment projects.

Although the data obtained as a result of the study reveal the current situation and expectations regarding the scope and period of the relevant study, it should be considered as a reflection of the expected characteristics for office investments in general. For the office investments to be made, it is recommended to conduct detailed research on feasibility and investability and to provide demand analysis. According to the developers and designers, it has been noted that they have expressed their opinion that the functional structures for the new offices to be produced in Ankara should be economical in terms of initial production and usage cost. In fact, it has been evaluated that this situation is directly related to the correct design of the buildings in terms of design and the limitation of energy use within the scope of the activities carried out. Therefore, it should be expected that energy conservation-oriented designs will be realized in the investments to be made.In the study carried out, it is understood that there is a need to produce new office buildings in Ankara for the near term, and the features that office investments should have been determined as providing technical infrastructure, social facilities, parking and valet services, and being able to divide or expand the spaces if needed. It has been evaluated that successful office projects can be produced if these features are taken into account in the studies to be carried out. However, in order for office projects to be successful investments, it is a necessity to develop the right management strategies with a focus on facility management and to implement design setups in which the cost of use is minimized with rational methods. Under these conditions, it is foreseen that sustainability strategies will be integrated into buildings, the economic life of new buildings will be extended with the right maintenance and usage methods, and the preferability of investments that prioritize energy-water-waste management and user comfort and the rental money will be higher.

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A bibliometric analysis of project complexity research in the construction industry

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Abstract. Given its significant implications for project management practices, resource allocation, and overall project success, project complexity has emerged as a critical area of inquiry. This study presents a bibliometric analysis of research on project complexity within the construction industry. Utilizing the Web of Science Core Collection database (WoS), a systematic search strategy was adopted to construct a comprehensive dataset, targeting peer-reviewed articles, reviews, and proceedings published within a defined time frame. The search string was designed to capture three dimensions: the concept of complexity in projects, strategies for coping with complexity (e.g., defining, managing, and assessing), and a focus on the construction industry. 615 publications were analyzed, leveraging the R-based tool Bibliometrix for bibliometric analysis. The analysis employed several bibliometric indicators, including publication output, citation analysis, co-authorship analysis, keyword co-occurrence analysis, and thematic clustering. The findings reveal the evolution of research on project complexity, highlighting key thematic areas, emerging trends, and gaps in the literature. Significant insights are drawn regarding the interplay between project complexity and management strategies within the construction domain. By mapping the intellectual structure and knowledge evolution, this study contributes to a comprehensive understanding of the field, offering a foundation for future research. The findings aim to inform researchers and practitioners by presenting a detailed overview of the current research landscape.

Keywords: Project complexity; Construction Industry; Bibliometric Analysis; Project Management

1. Introduction

Project complexity has become a critical challenge in the construction industry due to technological advancements, globalization, and rising stakeholder demands (Luo et al., 2017). As projects increase in scale, managing this complexity is vital for effective resource allocation, risk management, and successful outcomes (Williams, 1999). However, the research on project complexity in construction is vast and fragmented, requiring a clear synthesis of the field.

This study uses bibliometric analysis of 615 publications from WoS (between the years 1996 and 2024) to map the field's intellectual structure and thematic evolution. Our goals are to identify key contributors, thematic clusters, and emerging trends, providing insights for researchers and practitioners to advance this important area.

The remaining sections are as follows: Section 2 details the methodology, encompassing the data source, search strategy, and bibliometric indicators employed. Section 3 presents the results, including descriptive statistics, productivity, citation analyses, network analyses, and thematic mappings. Section 4 discusses the implications of these findings for research and practice, spotlighting key trends and future directions. Finally, Section 5 summarizes the study's contributions and recommendations for advancing the field.

2. Methodology

The methodology adopted in this study was designed to ensure a systematic and reproducible approach to data collection, processing, and analysis. The data collection begins with selecting a robust and credible data source, then constructing a well-defined search string and applying precise filters and refinements to narrow the scope of the dataset. Data extraction was conducted with attention to detail, ensuring all relevant bibliometric information was retained for analysis. The study employed an advanced bibliometric software package to process and

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analyze the data, leveraging bibliometric indicators and visualization techniques to uncover patterns, trends, and key insights. This section outlines each step, providing transparency and rigor to the methodological framework.

Data Source: WoS is utilized for the analysis due to its extensive coverage of high-impact, peer-reviewed journals and robust indexing standards (Feng et al., 2024; Issrani et al., 2024). WoS is a trusted resource for analyzing scholarly trends and networks, ensuring the dataset's reliability and relevance.

Search String: It was crafted focusing on three key dimensions: (1) project complexity in the context of systems thinking, (2) how to address this complexity (e.g., defining, measuring, managing), and (3) the construction industry. Core terms were combined with Boolean operators (AND, OR) and wildcards (e.g., "complex*" for variations). The final search string—("project complex*" OR "complex projec*" OR "complexity of projec*" OR "complexity in projec*" OR "system complex*") AND (manag* OR defin* OR measur* OR assess* OR evaluat* OR quantif*) AND ((construction OR building) AND (indust* OR sector* OR project*))—captures the research scope effectively, ensuring inclusivity across relevant studies.

Filters and Refinements: To ensure the dataset's relevance, a series of filters and refinements were applied to create a comprehensive yet targeted dataset aligned with research objectives. The search was restricted to "topic, abstract, and keywords" fields. Only English-language "articles, proceedings, and reviews" were included, ensuring a focus on credible, peer-reviewed sources. Timespan was limited to publications since 1996, when project complexity emerged as a key research topic (Baccarini, 1996; Gidado, 1996). The dataset was further refined through "Research Areas" and "WoS Categories", targeting construction and management-related fields.

Data Extraction: On 30 December 2024, 615 publications, including full records and cited references, were exported as a BibTeX file. The BibTeX format provides a structured and standardized organization of bibliographic data, making it highly compatible with bibliometric tools and allowing seamless data processing. Exporting the "full record and cited references" enables a comprehensive bibliometric analysis for the research.

Analysis Tool: Bibliometrix, an R-based package, is selected over other tools like VOSviewer or CiteSpace for its robust capabilities in data processing, analysis, and visualization (Aria & Cuccurullo, 2017). It provides a broader range of analyses, is open-source, and also integrates seamlessly with other R packages such as ggplot2 for advanced visualizations, dplyr for data manipulation, and tm for text mining. Additionally, embedding it within a code-driven markdown framework (Fig. 1) enables a traceable, replicable, and adaptable process.

Bibliometric Indicators: To gain a comprehensive understanding of the dataset, a range of bibliometric indicators and visualization techniques were employed (Donthu et al., 2021; Öztürk et al., 2024):

- **Descriptive Analysis (General Overview):** It provides an overview of the research field by summarizing key dataset characteristics, such as the number of documents, document types, and timespan. It also analyzes temporal trends in publication using a line graph to identify milestones and developments.
- **Performance Analysis (Productivity and Citation Analysis):** It evaluates the productivity and citation impact of authors, institutions, and countries. It visualizes the geographical distribution of publications, identifies prolific and highly cited authors, and assesses the most influential journals.
- **Network Analysis (Science Mapping):** It reveals collaboration patterns by co-authorship, research schools by co-citation or bibliographic coupling, and major research areas by keyword co-occurrences. Networks represent relationships between entities, where the size of each node indicates its importance or connectivity within the network, and the edges show interactions.
- **Thematic Analysis (Research Theme Analysis):** It investigates the evolution of research themes by examining temporal trends in keyword usage to trace topic development and identify emerging and declining themes. It offers a structured view of the field's thematic landscape.

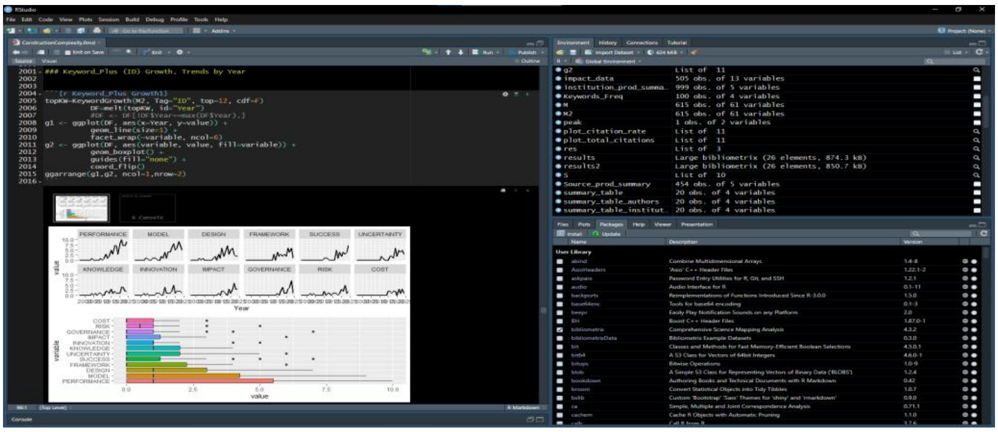

Fig. 1. R Markdown Environment Utilized During the Bibliometric Analysis

3. Results

As described in Table 1, the dataset encompasses 615 publications (between the years 1996 and 2024) on construction project complexity, offering a robust foundation for bibliometric analysis. The distribution of document types suggests that journal articles (417) are the primary medium for disseminating research in this field. At the same time, proceedings papers (162) indicate active participation in conferences, and reviews (28) provide a consolidated understanding of the field, adding depth to the analysis. The documents are sourced from 278 distinct outlets (journals, conferences), highlighting the interdisciplinary nature of the research. Spanning nearly three decades, it balances foundational and recent works (average publication age: 8.63 years), capturing evolving trends. Citation metrics (23.22 average citations per document) indicate strong scholarly impact, while 23,165 referenced works enable deep network analyses. The dataset's diversity, temporal breadth, and high citation activity highlight a thriving, interdisciplinary field with rich historical and emerging insights, ideal for mapping knowledge structures and trends.

The "Annual Scientific Production" graph (Fig. 2) illustrates the growth of research output. The research field evolved from a nascent phase with low, steady output (1996–2005) due to limited adoption of complexity theory and methodologies, followed by a sharp rise in publications during a mid-growth phase (2006–2015), and accelerated output in recent years (2016–2024). Research output has grown steadily at an annual rate of 12.42%, with a notable acceleration starting around 2006 and a peak around 2020, followed by some fluctuations in recent years. This upward trend highlights the topic's increasing academic interest and relevance over time, reflecting a maturing research domain with significant scholarly contributions.

Table 1. Key Dataset Metrics and Interpretations for Project Complexity Research

Metric	Value	Interpretation
Number of Documents	615	Represents a substantial dataset for analysis, indicating significant scholarly attention to the topic.
Document Types	Articles: 417; Proceedings Papers: 162; Reviews: 28; Article + Proceedings Paper: 8	Highlights the dominance of journal articles, active conference engagement, and contributions of review papers to synthesize knowledge.
Timespan	1996–2024	Reflects nearly three decades of research, allowing for an analysis of historical evolution and emerging trends.
Number of Sources	278	Indicates diverse publication outlets, demonstrating interdisciplinary interest in the field.
Average Years from Publication	8.63	Suggests a balance of older foundational works and recent research, enabling retrospective and contemporary analysis.
Average Citations per Document	23.22	Highlights a reasonable level of impact, with documents being widely cited and acknowledged in the research community.
Number of References	23,165	Indicates extensive cross-referencing, providing opportunities for network analyses to identify influential works.

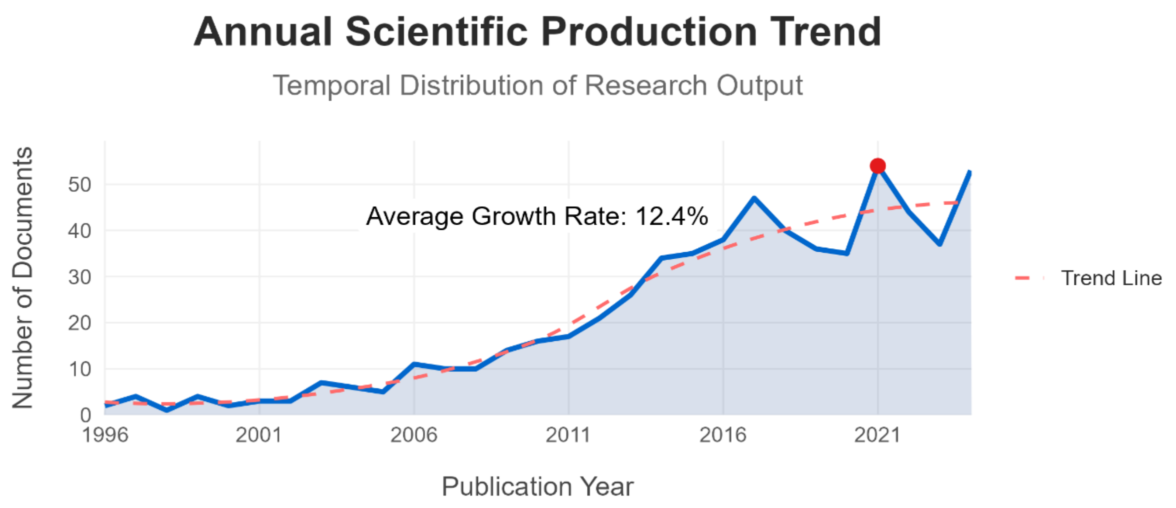

Fig. 2. Annual Scientific Production Trend of Publications Over Time

3.1. Global Research Productivity, Impact, and Collaboration Patterns

As shown in Fig. 3, the United States leads global scientific output, producing 115 publications (18.85% of total output), predominantly single-country papers, reflecting a strong independent research focus. China follows with 102 publications and a higher multi-country publication (MCP) ratio of 0.31, indicating significant international collaboration. Malaysia stands out with an MCP ratio of 0.50, and Australia (0.38) also emphasizes cross-border partnerships. Conversely, Brazil and the Netherlands prioritize independent research, with low MCP ratios.

Regarding impact, the USA (2,571 total citations) and China (2,209) top the citation charts due to their volume. Canada (42.75) and the Netherlands (30.08) excel in average citations per publication, suggesting higher research quality. Smaller producers like Singapore and Sweden also achieve notable citation averages.

At the institutional level, Tongji University (China) leads in productivity (14.09 fractional output) with 330.23 total fractional citations. Hong Kong Polytechnic University (China), despite lower output (6.62), achieves the highest average citations (61.21) and 405.03 total citations. Delft University of Technology (Netherlands) balances moderate output (8.57) with consistently high citations (33.06 average), whereas Arizona State University (USA) is ranked third in fractional productivity (8.00), yet with lower average citations (3.63).

The collaboration network (Fig. 4) identifies China (degree centrality 0.737), the UK (0.684), the USA (0.632), and Australia (0.579) as central hubs. Three clusters emerge, revealing regional collaboration patterns: a European (e.g., UK, France), an Asia-Pacific (e.g., Australia, Malaysia), and a USA-China-led cluster.

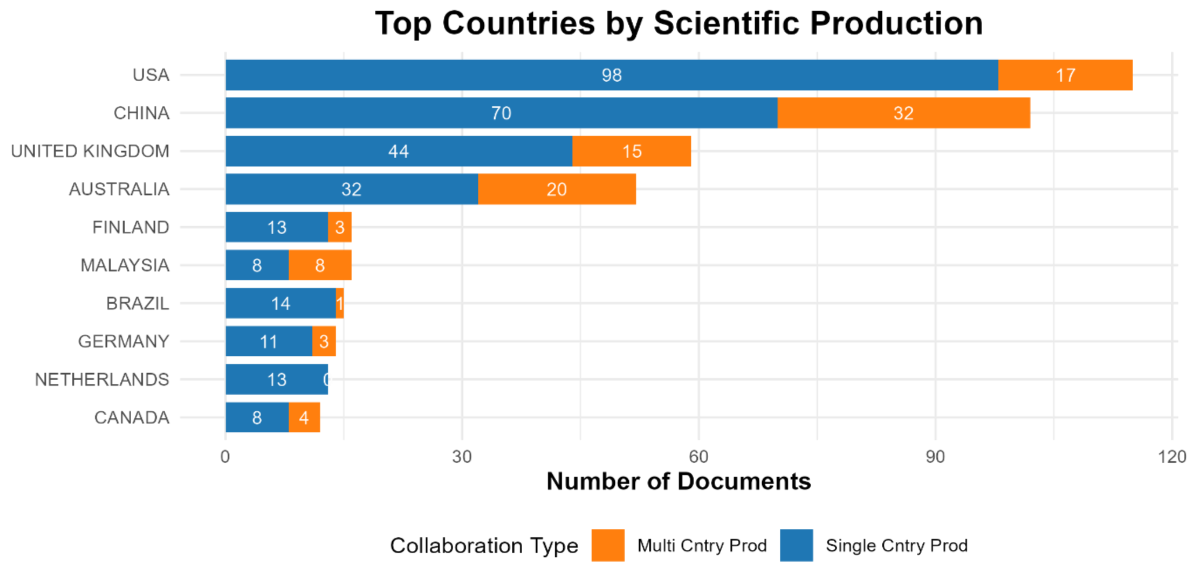

Fig. 3. Top Countries by Scientific Production in Project Complexity Research

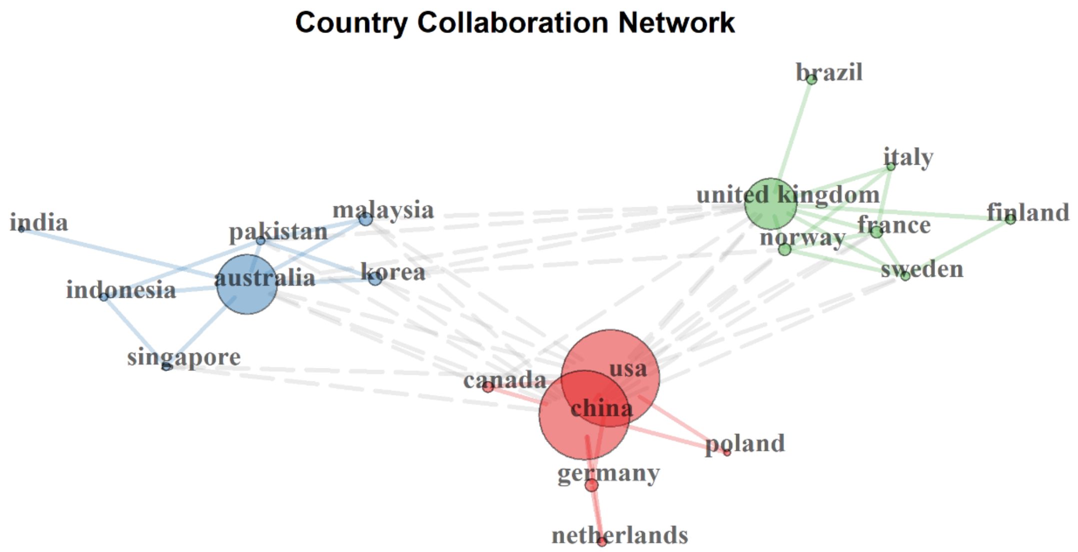

Fig. 4. Country Collaboration Network Visualizing International Research Partnerships

3.2. Leading Authors: Productivity, Impact, and Intellectual Connections

This section analyzes key researchers based on their publication output, citation impact, and intellectual connections. Fig. 5 depicts the publication timelines of the top 20 authors, with each horizontal line spanning from the earliest to the latest year of publication. Circle sizes indicate the contribution in a given year, while the color scale represents total citations per year, with darker hues signifying higher citation intensity.

Zhang L. and Kermanshachi S. top the list as the most prolific authors, each with 12 publications. Zhang L. has a significantly higher citation impact, receiving 821 total citations (averaging 68.42 citations per paper), while Kermanshachi S. has 252 citations. Other notable contributors include Luo L. (7 publications) and Skitmore M. (6 publications). Despite fewer publications, Davies A., Le Y., and Chan Apc. achieve a high average of citations. Davies A. leads with 92 citations per paper. Publication timelines reveal that authors like Zhang L. maintain consistent output and high citations over time. In contrast, others, such as Davies A. and Le Y., produce fewer but highly impactful works, reflected in larger or darker markers for specific years.

The author coupling network (Fig. 6), based on shared references, identifies thematic clusters among 40 researchers with a moderate connection density (0.237) and high clustering (0.496). Central Fig.s like Luo L. (degree centrality 0.949), Kermanshachi S. (0.744), and Zheng J. (0.615) bridge these clusters, facilitating knowledge exchange across the field.

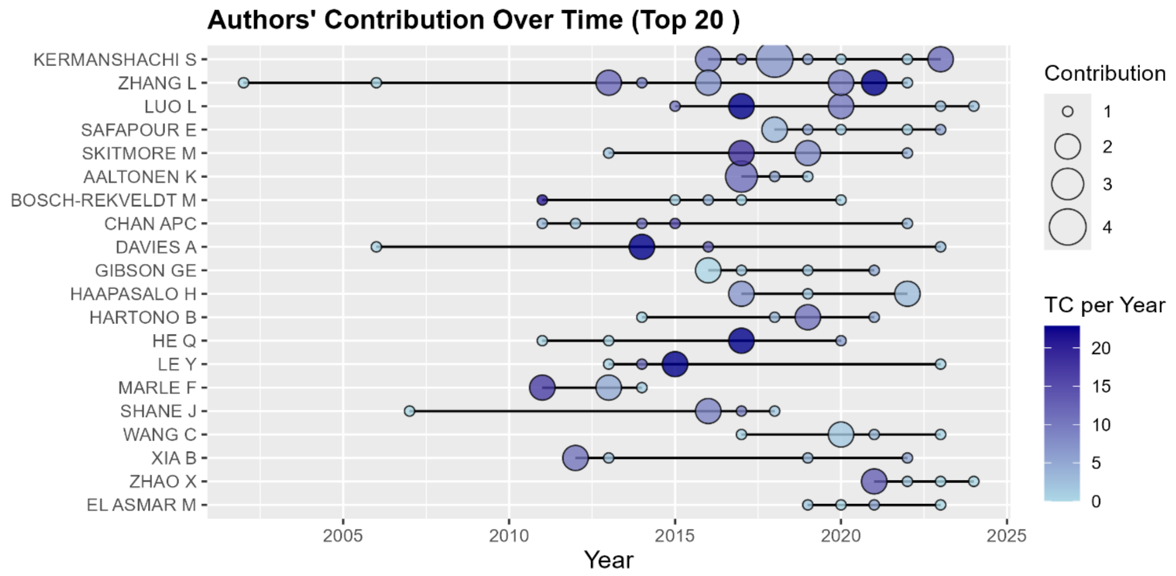

Fig. 5. Top 20 Authors' Contribution Over Time with Publication and Citation Trends

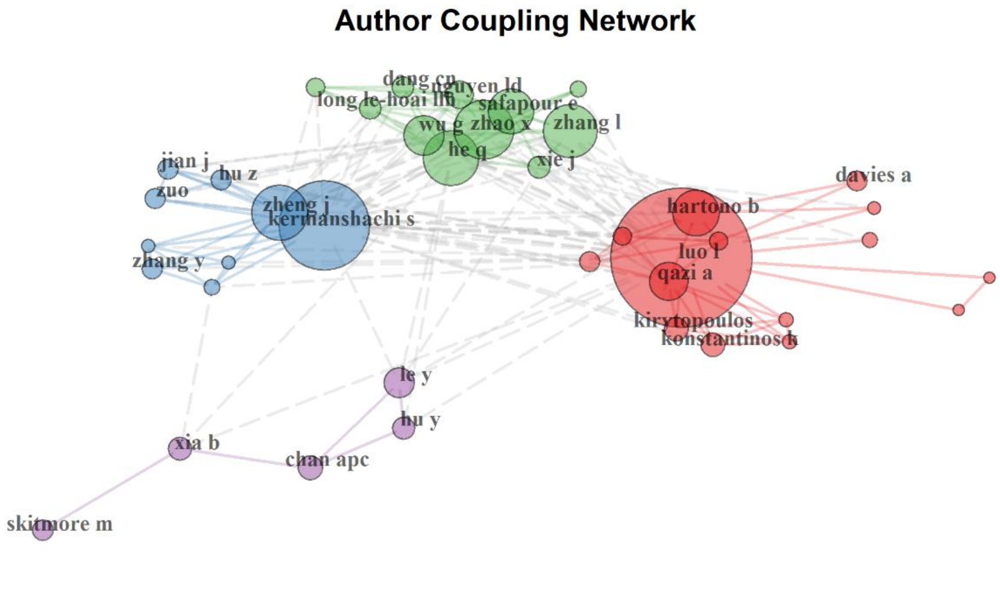

Fig. 6. Author Coupling Network Illustrating Thematic Commonalities Among Researchers

3.3. Key References and Publications

As for the references for a historical perspective, Table 2 highlights that the International Journal of Project Management emerges as the leading journal with 2,705 frequencies, far ahead of the Journal of Construction Engineering and Management (895) and Journal of Management in Engineering (763), reflecting its pivotal role in shaping project management scholarship. Among authors, Williams T. tops the list with 170 citations, followed by Flyvbjerg B. (140) and Love P. (126), underscoring their significant contributions.

Reference Publication Year Spectroscopy (RPYS) in Fig. 7 reveals the field's historical foundations by presenting the accumulation of references over time (Marx et al., 2014). There is a sparse amount of references before the 1970s, a gradual increase in the 1980s, and a sharp rise from the 1990s onward, indicating an expanding body of literature. A slight decline near 2020 suggests a typical citation lag for recent works. The years with unusually high or low citation rates point to landmark publications or shifts in research focus.

Fig. 8 (Reference Co-Citation Network) illuminates which specific works served as pivotal references, illustrating how frequently cited works form clusters based on how often they are referenced together. Three main clusters emerge, visible in color-coded groupings.

- **Cluster 1 (Red)** (12 documents, total referencing = 578, average referencing = 48.17) hosts the most influential references overall, as evidenced by Baccarini (1996)—the highest-degree node (0.2136) with 115 citations—and other key works by Williams (1999), Bosch-Rekveldt (2011), and Vidal (2011). These publications often define or refine conceptual underpinnings in project complexity, scope, and definition, thus anchoring the broader literature.
- **Cluster 2 (Blue)** (13 documents, total referencing = 412, average referencing = 31.69) consists of more recent studies, such as He (2015), Bakhshi (2016), Qazi (2016), and Luo (2017), which collectively focus on conceptualizing and measuring project complexity, while also examining emerging trends and implications in this domain. Although the average citation count here is lower than in Cluster 1, several nodes (e.g., Luo 2017) display relatively high individual citation Fig.s and centralities, underscoring their growing importance.
- **Cluster 3 (Green)** (5 documents, total referencing = 121, average referencing = 24.20) is smaller but includes influential works by Flyvbjerg (2014) and Davies (2014), often linked to mega-project governance, cost overrun debates, and the strategic management of large-scale projects. Despite fewer member references, the cluster maintains a moderate average centrality (0.0718), suggesting a cohesive sub-field interacting with the other two clusters.

Table 2. Top 10 Most Referenced Sources and Authors in the Dataset

Source	Frequency	Author	Frequency
Int J Proj Manag	2705	Williams T.	170
J Constr Eng M	895	Flyvbjerg B.	140
J Manage Eng	763	Love P.	126
Proj Manag J	640	Baccarini D.	124
Automat Constr	577	Vidal L.	119
Constr Manag Econ	479	Geraldi J.	104
J Constr Eng M Asce	457	Davies A.	100
Eng Constr Archit Ma	368	Shenhar A.	98
Int J Manag Proj Bus	283	Boschrekveldt M.	87
J Clean Prod	188	Luo L.	80

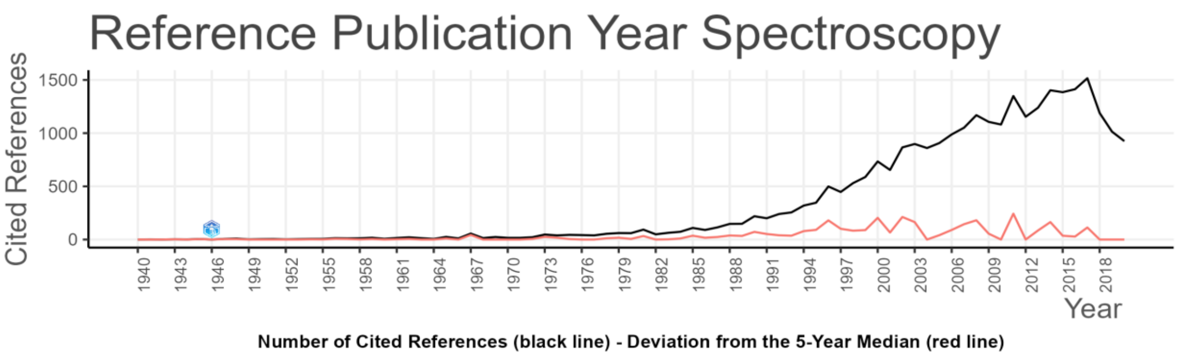

Fig. 7. Reference Publication Year Spectroscopy Showing Historical Citation Patterns

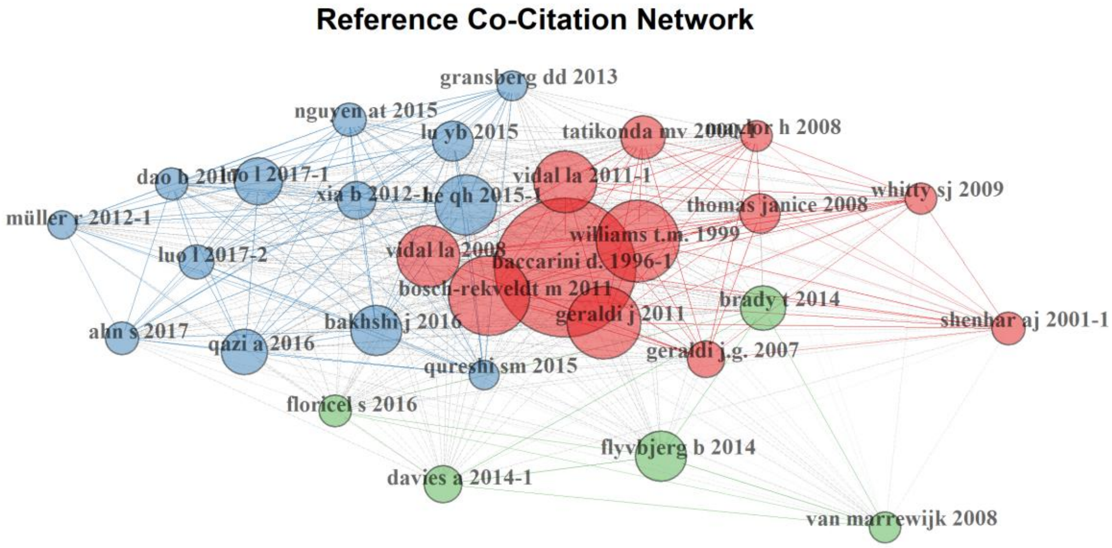

Fig. 8. Reference Co-Citation Network Depicting Clusters of Influential Works

For publications within the dataset, the Reference Coupling Network (Fig. 9) identifies three tightly coupled clusters. The network illustrates a multifaceted research landscape integrating measurement, theory, and practice.

- **Cluster 1 (Red) - Measuring Project Complexity:** (14 papers, total citations = 1,105, avg = 78.93) This cluster quantifies complexity and its impact, emphasizing early diagnosis for better decision-making. For instance, Qazi (2016) and Luo (2017) propose quantitative tools for mapping complex environments and clarifying risk pathways, while Zhao (2021) and Mirza (2017) explore the direct link between complexity factors and performance shortfalls.
- **Cluster 2 (Green) – Investigating Complexity–Success Relationships: (**11 papers, total citations = 305, avg = 27.73) This cluster features systematic reviews or advanced conceptual frameworks (bibliometric methods, DEMATEL, fuzzy logic, or qualitative comparative analysis) that examine the dimensional structure of complexity and its link to success (Ghaleb, 2022; Kim, 2021; Zheng, 2023; Ma, 2020). It is a nexus for synthesizing knowledge and understanding the multidimensional nature of complexity.
- **Cluster 3 (Blue) - Managing Complexity in Megaprojects: (**15 papers, total citations = 594, avg = 39.6) This cluster emphasizes managerial strategies for megaprojects. It highlights adaptive approaches, leadership, and theories to address project challenges (Maylor, 2017; Davies, 2016; Eriksson, 2017; Daniel, 2019; Hartono, 2019–2). These papers often build on complexity theory, stressing collaborative approaches, dynamic capabilities, and stakeholder alignment to improve project outcomes.

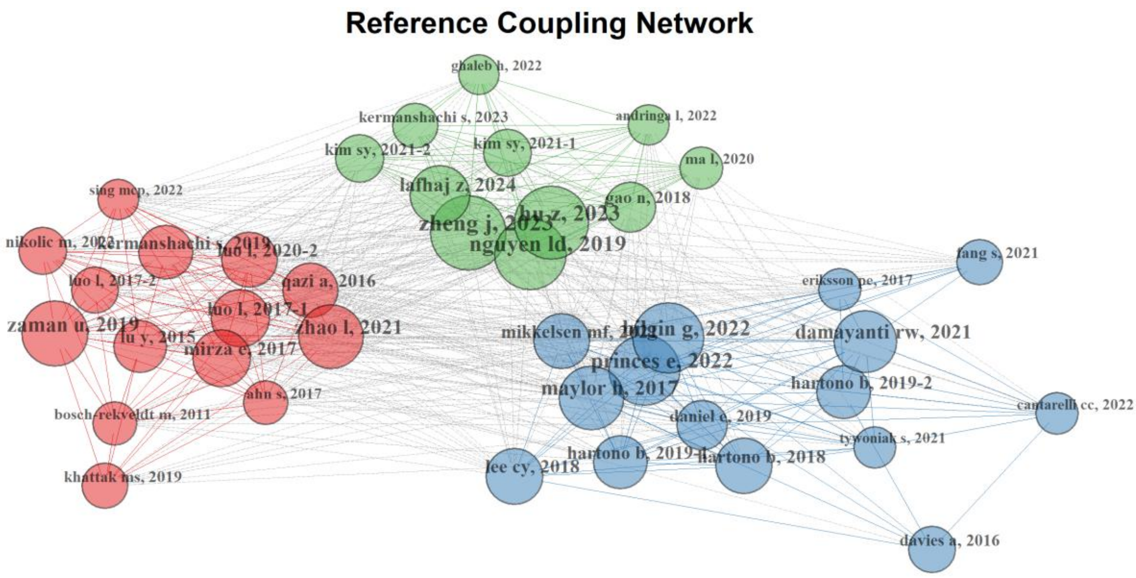

Fig. 9. Reference Coupling Network Revealing Thematic Linkages Among Studies

Fig. 10 analyzes the publication's impact through a scatter plot. The vertical axis shows total citations (scholarly influence over time), while the horizontal log-scaled axis tracks citations per year (recent impact). Bubble sizes reflect local citations (community relevance). The visualization aids in identifying key publications, mapping trends, and understanding the scholarly landscape. Several distinct patterns emerge from this visualization:

- **High global, low local impact:** Pan (2021), Singh (2011), Muller (2010), and Edmondson (2009) in the upper-right quadrant have high total citations but minimal local citations. These works have achieved significant global recognition, likely due to their broad applicability or foundational contributions across disciplines; however, they are not central to the current community focus.
- **Balanced global-local influence:** Bosch-Rekveldt (2011), Luo (2017), Qazi (2016), Vidal (2011), Brady (2014), and Davies (2014) strike a balance between significant total citations and high local citation counts. These works likely serve as intellectual pillars shaping the field's core frameworks.
- **Moderate dual impact:** Carvalho (2017), Sommer (2004), and Pitsis (2003) show mid-range citations globally and locally. These works likely contribute valuable insights yet lack the transformative impact of more foundational references. They play a supporting role, enriching the field.
- **Emerging works:** Positioned in the bottom-right quadrant, publications like Ghaleb (2022), Zhu (2022), and Afzal (2021) exhibit high citations per year but low total counts. These recent papers have a potential for increased impact as more scholars incorporate these findings into their research,

Table 3 ranks papers using a Composite Normalized Citation Score (CNCS) crafted by authors. It averages normalized total citations, citations per year, and local citations (each scaled 0–1). This balanced metric identifies top-performing works across all dimensions (total citation count, yearly citation rate, and local relevance), offering a concise guide to influential publications.

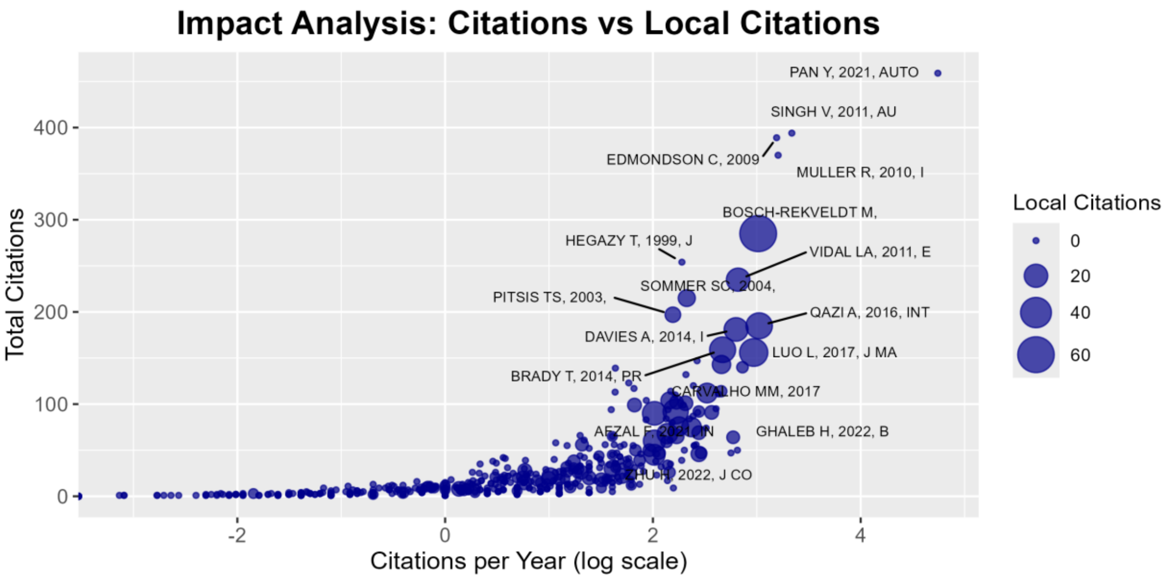

Fig. 10. Impact Analysis: Total Citations vs. Local Citations of Publications

Table 3. Top 10 Documents Ranked by Composite Normalized Citation Score

Publication (First Author, Year, Journal)	CNCS	TC	TCpY	LCS
Pan Y, 2021, Autom Constr	0.67	459	114.75	0
Bosch-Rekveldt M, 2011, Int J Proj Manag	0.60	285	20.36	61
Singh V, 2011, Autom Constr	0.37	394	28.14	0
Luo L, 2017, J Manage Eng	0.34	156	19.50	32
Qazi A, 2016, Int J Proj Manag	0.34	185	20.56	27
Muller R, 2010, Int J Proj Manag	0.34	370	24.67	0
Vidal La, 2011, Expert Syst Appl	0.33	235	16.79	20
Brady T, 2014, Proj Manag J	0.30	159	14.45	26
Davies A, 2014, Int J Proj Manag	0.29	181	16.45	21
Sommer Sc, 2004, Manage Sci	0.23	215	10.24	8

CNCS: Composite Normalized Citation Score; TC: Total Citation; TCpY: Total Citation per Year; LCS: Local Citation Score

3.4. Most Relevant Keywords

Table 4 lists the Top 10 frequent Author Keywords (DE) and Keywords-Plus (ID). DE reflects author-emphasized themes, while ID (algorithmically generated by WoS) captures latent patterns from citation contexts. It is critical to note that terms such as "complex, complexity, system, project, management, construction, and industry" were excluded to avoid redundancy from the original search string. Their omission ensures an analytical focus on supplementary themes rather than overrepresented terms inherent to the research domain.

The top DE keywords are "risk" (47) and "performance" (39), highlighting concerns in megaprojects (14) and infrastructure (13). Top ID keywords are "performance" (75) and "model" (67), emphasizing methodological trends like "design" (49) and "framework" (36). Overlaps—"performance, success, uncertainty, innovation, knowledge"—show shared priorities, revealing a field focused on contextual challenges (DE) and methodological approaches (ID).

Fig. 11 "Author Keywords (DE) Co-occurrence Network" provides a thematic structure within the domain. This analysis identifies "risk" and "performance" as central hubs (highest centrality), connecting the sub-themes. Their prominence implies that risk assessment and performance evaluation are pivotal concerns, likely framing the broader discourse in megaproject or infrastructure research. Four distinct theme clusters emerge:

- **Risk Management and Planning** (risk, uncertainty, planning, scheduling, control, theory, building): Focuses on mitigating uncertainties in project execution.
- **Performance and Collaboration** (performance, collaboration, infrastructure, BIM, design, safety, cost): Emphasizes optimization via collaboration and technology.
- **Innovation and Knowledge Management** (innovation, success, communication, knowledge, information, case study): Highlights innovation and knowledge-sharing for success.
- **Analytical Approaches and Optimization** (analysis, megaprojects, dynamics, optimization, decision making, simulation): Centers on analytical methods for megaprojects.

Table 4. Top 10 Author Keywords (DE) and Keywords-Plus (ID) by Frequency

Author Keywords (DE)	Freq (DE)	Keywords-Plus (ID)	Freq (ID)
Risk	47	Performance	75
Performance	39	Model	67
Success	17	Design	49
Uncertainty	17	Framework	36
Innovation	14	Success	33
Megaprojects	14	Uncertainty	33
Infrastructure	13	Knowledge	30
Analysis	12	Innovation	27
Collaboration	12	Impact	25
Knowledge	12	Governance	24

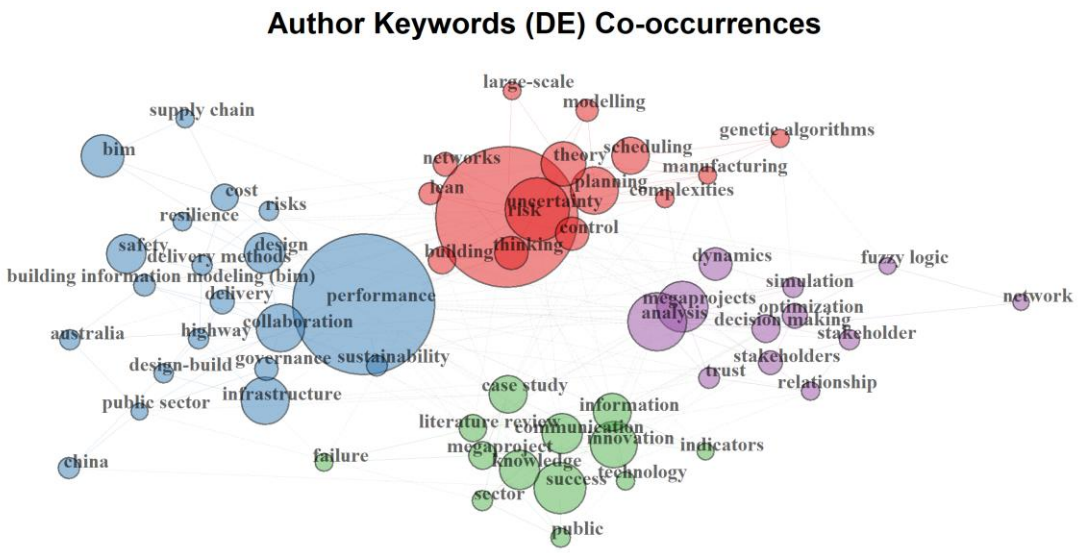

Fig. 11. Author Keywords (DE) Co-occurrence Network Highlighting Thematic Clusters

3.5. Thematic Evolution

The plot (Fig. 12) tracks top DE keywords' temporal distribution and frequency from 2008 to 2023. Horizontal lines show the publication year range (from quartile 1 to quartile 3), with dots marking the median year and sized by frequency. Three phases emerge: **(1) 2008–2014;** early focus on "modelling" and "China", with narrow spreads (6–8 years) and low frequencies (≤10), signaling foundational regional/methodological studies, **(2) 2015–2018;** peak activity with "risk" (frequency 47), "performance" (39), "uncertainty," and "infrastructure," reflecting prioritization of risk management and performance metrics, **(3) 2019–2023;** shift toward "success, megaprojects, stakeholder, supply chain, and sustainability", with moderate frequencies (6–17), highlighting emerging social/environmental priorities. In terms of temporal spread, sustained themes (risk, performance) show broad temporal spans (9–10 years), while recent terms (sustainability, supply chain) have shorter spreads (2–4 years), indicating concentrated modern interests.

The thematic map (Fig. 13), which is based on the work of Cobo et al. (2011), categorizes research themes into four quadrants by development density (maturity) and centrality (influence). This approach offers a comprehensive snapshot of the current research landscape, highlighting well-established topics, foundational areas with growth potential, emerging or fading trends, and specialized niches. Below, each quadrant is explained with its characteristics and associated themes:

- **Motor-Themes (Upper-Right: High density/centrality):** Mature, influential themes include project complexity management, multi-criteria multi-insight, verbal decision analysis, Delphi method, and transport. These topics serve as foundational pillars guiding both research and practice.
- **Basic Themes (Lower-Right: High centrality, low density):** Broadly relevant but underdeveloped themes like large-scale complex projects, procurement, risk management (e.g., risk process, risk factors), and tools (BIM, blockchain, digital twin) offer growth potential.
- **Emerging/Declining Themes (Lower-Left: Low density/centrality):** Themes such as social network analysis, coordination, systematic literature review, and Australia may be emerging (e.g., social network analysis) or fading.
- **Niche Themes (Upper-Left: High density, low centrality):** Well-developed, narrow themes like agile project management, construction disputes, infrastructure projects, and transaction cost economics provide specialized insights with limited broad impact.

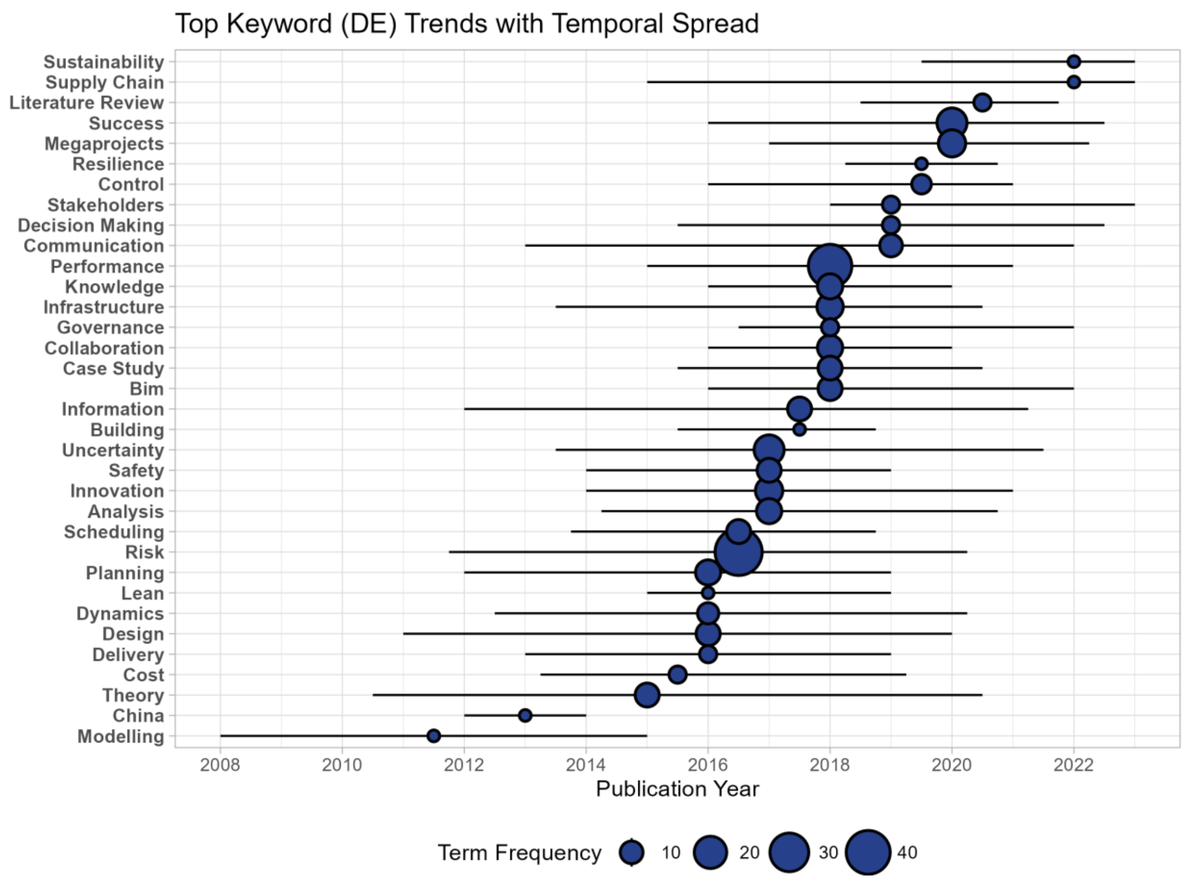

Fig. 12. Temporal Trends of Top Author Keywords (DE) from 2008 to 2023

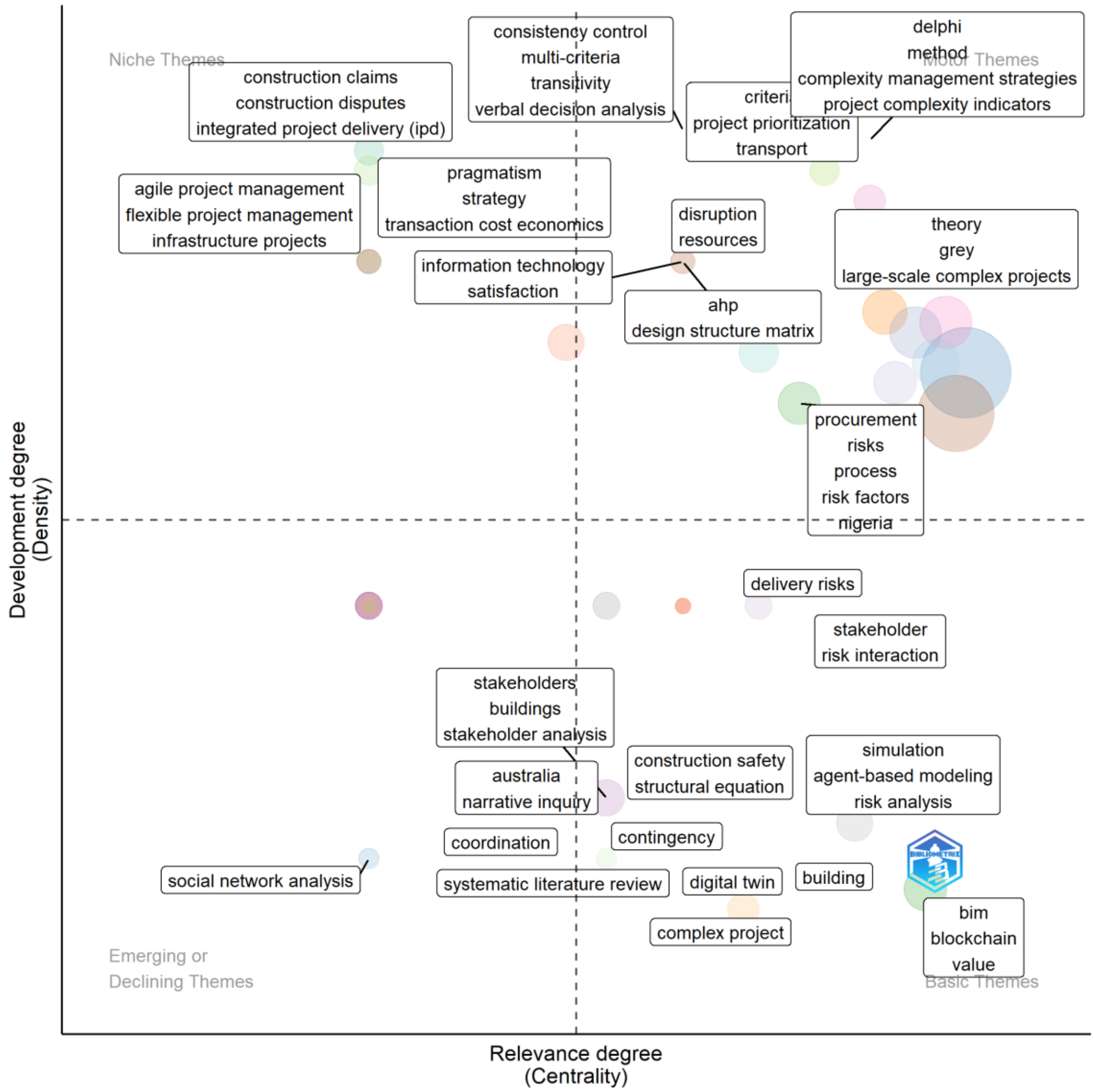

Fig. 13. Thematic Map of Research Themes Derived from Co-word Analysis

4. Discussion

This bibliometric analysis of 615 publications from 1996 to 2024 examines project complexity in construction. It reveals a significant rise in research output (12.42% annual growth), especially since 2006. This increase likely reflects modern project demands driven by technological advancements, globalization, and complex stakeholder interactions.

Geographically, the U.S. (115 publications) and China (102) dominate, representing >35% of output. The U.S. favors single-country studies (MCP ratio: 0.15), while China prioritizes international collaborations (MCP: 0.31). Institutionally, Tongji University leads in output (14.09 fractional count), but Hong Kong Polytechnic University achieves a higher citation impact (61.21 vs. 23.43). Author coupling networks highlight Zhang L. (12 papers, 821 citations) as more influential than Kermanshachi S. (12 papers, 252 citations), with Luo L. (degree centrality: 0.949) bridging interdisciplinary clusters.

Citation patterns highlight the International Journal of Project Management (2,705 references) and authors like Williams T. (170 citations) and Flyvbjerg B. (140 citations) as field cornerstones since the 1990s, which is also recognized from the RPYS plot as a timeline. The reference co-citation network reveals thematic clusters: one centered on defining and measuring complexity (e.g., Baccarini, 1996), another on conceptualizing and assessing it (e.g., Luo, 2017), and a third on managing large-scale projects (e.g., Flyvbjerg, 2014). These clusters indicate a maturing field that spans theoretical grounding and practical application.

The keyword analysis provides further insight into thematic priorities. "Risk" and "performance" emerge as central themes across both Author Keywords (DE) and Keywords-Plus (ID), with frequencies of 47 and 39 for DE and 75 and 33 for ID, respectively. Their prominence indicates the field’s focus on mitigating risks and optimizing project outcomes. The temporal evolution of keywords—from early emphases on "modelling" and

"China" (2008–2014) to "risk" and "performance" in the mid-2010s, and recently "success", "megaprojects", and "sustainability" (2019–2023)—illustrates a progression from foundational or regional explorations to applied and contemporary concerns. This shift suggests that researchers are increasingly addressing broader societal challenges, such as sustainability, within the context of complex construction projects.

Despite these insights, the study acknowledges certain limitations. The exclusive use of the WoS database may omit relevant works from other sources, potentially skewing the representation of the field. The focus on English-language publications could introduce a linguistic bias. The dominance of the U.S. and China-based papers could result in a geographical bias. While bibliometric analysis excels at mapping the research landscape, it offers limited qualitative depth into the content of individual studies, necessitating complementary approaches for a fuller understanding. Deepening the interpretation of thematic shifts and maps would also add more insight (e.g., what are the factors for shifts? Industry crises, technological advancements, or influential publications).

5. Conclusions

This study synthesizes three decades of construction project complexity research, highlighting sustained growth (12.42% annual increase) and global leadership by the U.S. and China, with divergent collaboration strategies. Key contributors include Tongji University (volume) and Hong Kong Polytechnic University (impact), while authors like Zhang L. and journals like IJPM provide intellectual anchors. Seminal works by authors like Williams T. and Flyvbjerg B. further equip scholars to navigate the field's intellectual core. Thematic clusters emphasize risk management and performance, with emerging interests in sustainability and megaprojects signaling future directions.

In summary, this analysis maps the field's evolution, offering a roadmap to address growing complexity in global construction contexts and contributing a foundational understanding that can guide future scholarly and practical endeavors. The centrality of risk and performance highlights their critical role in managing complex construction projects. At the same time, the rise of sustainability and stakeholder-related themes suggests a need to integrate broader societal considerations into project management strategies.

Future research could explore these emerging areas in greater depth to advance the field, perhaps through qualitative studies or content analyses that complement the quantitative scope of bibliometrics. Other databases (e.g., Scopus) or non-English sources could be integrated to broaden the perspective.

Acknowledgments

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Place and space: conceptual transformations and philosophical approaches in architecture

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Abstract. In architecture, often described as the art of creating space and constructing place, the concepts of space and place hold a central and indispensable role. Spaces are designed and built to facilitate human life and accommodate various activities. Humans, occupying a pivotal position within architecture, shape their lives within these constructed environments. Thus, space and human existence are deeply intertwined in a mutually reinforcing relationship. Considering space and place—terms with multidimensional structures and varied meanings across disciplines—solely in terms of their physical characteristics within architecture is both reductive and incomplete. Such an approach risks objectifying space and neglecting the role of the subject. To maintain the integrity of the human-space relationship, it is essential to understand these two concepts in all their dimensions. This requires examining the relationship between space and place to explore how they derive meaning in contrast to one another. Accordingly, this study conducts a comparative analysis of these concepts, tracing their definitions, transformations, and evolutions throughout history from various disciplinary perspectives.

Keywords: Place; Space; Architecture

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1. Introduction

What is architecture? Renowned architect Louis Kahn defined architecture as "the ponderous creation of spaces." Similarly, Richard Meier stated, "Architecture is vital and enduring because it contains us; it describes space, space we move through, exit in and use." Greek architect and urban planner Stefanos Polyzoides, known as the father of New Urbanism, answered this question by saying, "Architecture is about building a place in the universe, not about mimicking a depleted, decrepit reality."

In The Dictionary of Architecture, Turkish architect and author Doğan Hasol describes architecture as follows: "The art of designing and constructing spaces to facilitate human life and sustain activities such as sheltering, resting, working, and entertaining by harmonizing functional needs with economic and technical possibilities through aesthetic creativity; in another definition, the art and science of designing and constructing buildings and the physical environment; structure and space design; briefly, the transformation of building action into art... Architecture is the activity of designing spaces and structures that organize the physical environment of settlements, ranging from shelters to urban dimensions" (Hasol, 2017, p.324).

It is evident that the various answers to the question "What is architecture?" generally converge on a common point: space and place. In architecture, whose fundamental action is known to be the creation of space and the construction of place, the concepts of space and place have always played leading roles. However, the reason for their prominence lies in their intrinsic connection to humans. Through spaces and places, people express their ways of living, even their very existence, and the resulting architecture profoundly impacts human beings. When we juxtapose Le Corbusier's statement, "Architecture is the starting point for anyone who wants to take humanity towards a better future," with Sir Winston Churchill's remark, "We shape our buildings; thereafter, they shape us," and Doğan Hasol's assertion, "Good people cannot be raised in bad spaces," it becomes clear that these thinkers emphasize architecture's role in shaping individuals, societies, and even the future of humanity. Therefore, to achieve good architecture, it is crucial to define and understand the concepts of space and place from various perspectives.

2. Materials and Methods

This study adopts a qualitative and theoretical research methodology, rooted in comparative philosophy and conceptual analysis. The research is primarily literature-based, involving the critical examination and synthesis of

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texts from philosophy, architecture, and social theory to trace the historical development and evolving meanings of the concepts of space and place.

The primary method involves an interpretative reading of canonical and contemporary works, including original philosophical texts by Plato, Aristotle, Descartes, Heidegger, Husserl, and Merleau-Ponty, as well as their subsequent interpretations by theorists such as Norberg-Schulz, Pallasmaa, Lefebvre, and Augé. These thinkers were selected due to their foundational roles in shaping spatial and place-related discourse across disciplines.

Academic sources such as peer-reviewed journal articles, doctoral dissertations, and books were systematically reviewed to construct a comprehensive theoretical framework. Special attention was given to etymological, historical, and phenomenological dimensions of the concepts, with a cross-disciplinary lens integrating philosophy, architecture, and urban theory.

The study does not involve empirical fieldwork but relies on the analytical comparison of texts, exploring how definitions, interpretations, and functions of space and place have transformed across time and schools of thought. This comparative approach aims to deepen our understanding of these concepts and their implications for architectural theory and practice.

To clarify the theoretical trajectory of this study, the following schema in Fig. 1, illustrates the main stages of the research and the key philosophical frameworks explored in each phase:

3. The Meanings of Space and Place

To embark on the journey of understanding and defining the concepts of space and place, it is logical to begin by exploring their linguistic meanings. When comparing the meanings of the terms "space" and "place," the distinction is more evident in some languages, while in others, it is more ambiguous, making differentiation difficult. For instance, in Turkish, the difference in meaning between these two terms is not explicit, and they are often used interchangeably, especially in everyday language. According to the Turkish Language Association, "mekân" (space) broadly refers to a place, a location, a home, a dwelling, or even outer space, whereas "yer" (place) is defined as the space or area occupied or that can be occupied by something or someone; a location, a surface walked on; a region, area, or place of residence; a state, position, or situation; a country; a workplace for earning a living; importance or significance; a mark; land suitable for construction; arable land; a location where an event occurs or will occur; and even the Earth itself.

In English, however, the terms "space" and "place" are recognized as distinct concepts despite overlapping semantic fields, making the distinction easier to identify. According to the Cambridge Dictionary, "space" is defined as an empty area, available vacant space, the continuous expanse in all directions around everything, outer space, or the physical distance between two people. In contrast, "place" refers to a specific area, city, or building, a suitable location, a house, a situation or state, a position in relation to others, or a role within an organization, system, or competition.

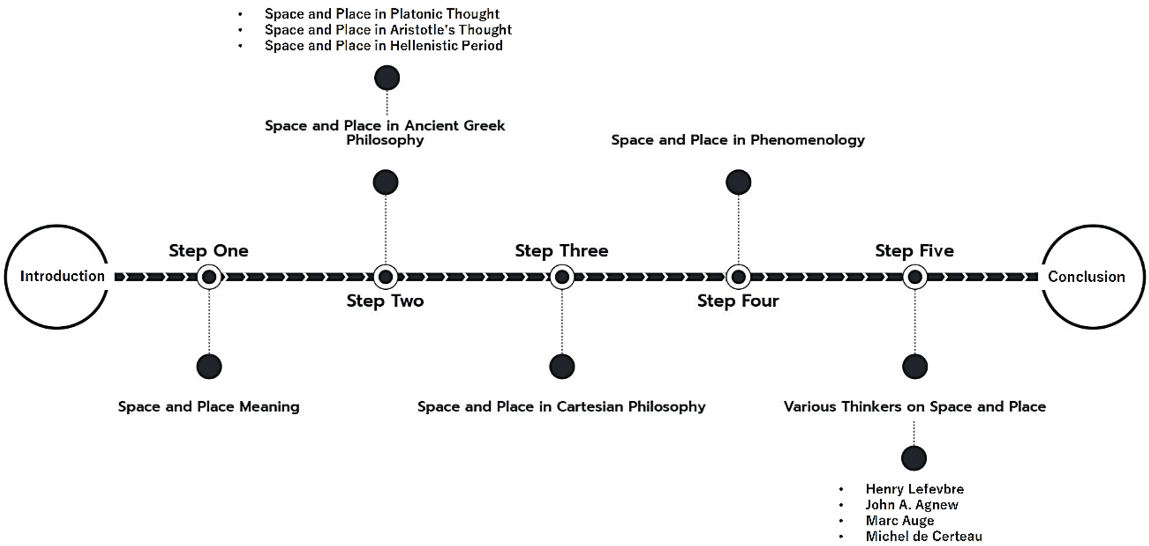

Fig. 1. Schematic diagram of the research process (visualized by the authors)

In Turkish, although "yer" and "mekân" may have different usages in some contexts, they appear to be synonymous in many others. As previously mentioned, in the field of architecture, these two concepts hold significant importance. Doğan Hasol's Encyclopedic Dictionary of Architecture defines "mekân" as "a space that separates humans to some extent from their physical environment and allows them to carry out their activities within it" and "yer" as "the surface of the earth, ground, land, or plot" (Hasol, 2017).

From this, we can conclude that to make a clear distinction between these two interconnected and multidimensional concepts and to understand how they derive meaning in relation to one another, it is necessary to delve into notable philosophical discussions throughout history. Such philosophical and conceptual inquiries are essential for a deeper comprehension. In line with this aim, the following section briefly introduces dominant philosophical approaches, particularly those from Western sources.

4. Space and Place in Ancient Greek Philosophy

4.1. Space and Place in Platonic Thought

The Ancient Greek philosopher Plato, one of the most influential figures in the history of philosophy, in his book *Timaeus* defines *khôra* as an indeterminate, receptacle-like medium that serves as the foundational "space" or "matrix" for the physical world. It is not a specific place but rather the condition of possibility for the existence of specific places (topoi). In contrast, *topos* refers to concrete, localized places within the physical world, where perceptible and affectable bodies occupy specific positions and interact within a defined geometry or locus (Plato, 360 BCE/2000; Casey, 1997).

When examining the epistemological origins of terms related to space, two key concepts emerge: *khora* and *topos*. The term *topos*, which shares the same root with words such as topography, topology, toponymy, utopia, and topic, is associated with location and is more closely linked to the notion of place. On the other hand, *khora*, which derives from the same root as technical terms like choreography, chronology, and chlorometry, inherently contains a temporal dimension. As a specific place, *khora* corresponds to the matrix of forms (Adıgüzel Özbek, 2016).

4.2. Space and Place in Aristotle's Thought

In *Physics*, Aristotle discusses *topos* (place) in a qualitative sense rather than *khora* and defines it simply as the portion of space occupied by a body (Nalbantoğlu, 2008). Aristotle rejects the idea of an empty place or an abstract concept of space in which nothing exists. Instead, he argues that place is always dependent on the relationship between bodies. Aristotle defines place (*topos*) as the boundary of the containing body that is in contact with the contained body. In other words, place is the innermost motionless boundary of what surrounds an object (Aristotle, 350 BCE/2000).

In Aristotelian philosophy, space is the natural location occupied by something in its movement, where its outer surface is in contact with the outer surface of another thing. In this sense, the place of an object encompasses and embraces it rather than being a space that enters into it or that the object itself occupies (Nalbantoğlu, 2008).

Aristotle's analogy—"To be in a place is very much like being in a vessel; place is something far beyond matter or form"—essentially describes the limitation of the body through the container's limiting function (Casey, 1997). The container represents the boundary or shape of a place, while the body serves as the shell of human existence (Tuncer Gürkaş, 2010). Referring to place as a kind of "container," Aristotle argues that the power of place lies in its ability to hold objects together. Objects without a place experience a form of loss, resulting in a kind of existential absence (Deviren, 2001). Thus, it is possible to conceive of space as a vast, all-encompassing physical form, while place consists of specific locations within this space, carrying meanings beyond being merely a form (Tuncer Gürkaş & Barkul, 2012).

Albert Einstein, who was significantly influenced by Aristotle's ideas, attempts to explain the difference between place and space through the example of a cherry crate. In this analogy, space can be thought of as the entity that holds the cherries within it—in this case, space is the crate itself. If we remove the cherries from this conceptualization, what remains is "space as a container." On the other hand, if space is conceived merely as an expansive area, an extension, or the part occupied by the cherries within the crate, then if we remove the crate from this thought experiment, what remains is "space as that which is contained" (Malpas, 2012).

4.3. Space and Place in the Hellenistic Period

The dominant philosophical perspective of the Hellenistic period, represented by the 'atomists,' asserted that nothing exists apart from atoms and the void. In relation to space, they introduced the concept of 'infinite space.' The atomist model posits a twofold infinity: the infinity of space itself and the infinity of the atoms that fill this space.

One of the most prominent thinkers of the period, Epicurus, countered the notion of infinite space by proposing three fundamental functions of general space: void, place, and room (*khôra*). Void refers to truly empty space, an unoccupied expanse. Place denotes occupied space and relates to the position of an object perceived within space. Room, translated from Plato's concept of khôra, signifies the medium within which movement occurs (Deviren, 2001).

5. Space and Place in Cartesian Philosophy

Newton's Mathematical Principles of Natural Philosophy, published at the end of the 17th century, marked a critical turning point in the distinction between space and place. Drawing from the disciplines of physics, mathematics, and geometry, Newton reduced the concept of place to position and advocated for the theory of absolute space (Deviren, 2001). According to Newton, "space is an absolute expanse independent of its contents and should not be confused with the objects within it" (Usta, 2020).

During the early modern period, two significant terms were introduced into discussions on space: extension and motion. Extension (or spatial expanse) was mathematized by Descartes. As explicitly stated in Principles of Philosophy, Descartes assimilated the reality of place into the abstraction of space. Place was reduced to mere position, while space emerged as a purely abstract concept (Deviren, 2001). In an era dominated by the natural sciences, physics, mathematics, and geometry, place came to be understood as position, while the theory of absolute space—rooted in Euclidean geometry—was defended, shaping a Cartesian understanding of space.

6. Space and Place in Phenomenology

Abraham Moles (1920–1992), one of the pioneers in the conceptualization of space, categorized the human relationship with space into two philosophical perspectives; "physical-mathematical space" which is based on Cartesian philosophy and "phenomenological space" (Seçer, 2016). In the physical-mathematical perspective, space is conceived as a homogeneous, three-dimensional void, independent of human experience and meaning. This view perceives space as an empty framework in which the human subject exists separately, acting as an impartial observer detached from the world. However, this fragmentation of the human-space relationship suggests a disconnection between individuals and their spatial environments. While mathematical models may provide an ideal framework for studying space, they prove insufficient when addressing the complexities of social existence. In contrast, the phenomenological understanding of space emphasizes lived experience, focusing on inhabited space or spatial experience. This perspective foregrounds the human body as the starting point, proposing a human-centered, directly perceived, and experience-driven conceptualization of space.

Along with phenomenological studies on place, the concept of pure and absolute space has undergone a significant transformation, gaining new meaning through the notion of movement. This phenomenon of movement also forms the core of the phenomenological approach developed by Edmund Husserl, the founder of phenomenology (Deviren, 2001). Husserl, who emphasized 'the necessity of bracketing preconceptions to achieve true understanding,' argued that understanding space requires experiencing it, and experiencing it necessitates movement within it. Experience, therefore, occurs through movement. Accordingly, he focused on the concept of place as dependent on kinesthetic perception, stating that "place is realized through kinesthesis, and in this reality, the character of place is optimally experienced" (Husserl, 1962). This perspective reveals that place is not merely a location but rather a complex whole. Consequently, in addition to the concept of movement, the notion of experience has also been integrated, making it an active component of place (Deviren, 2001).

According to Heidegger (1927) the state of being-in-a-place, or In-der-Welt-sein (being-there), is fundamental to human existence. It denotes the inseparable relationship between individuals and the world around them. For Heidegger, human beings are not detached from their environment; rather, their being is realized through their interaction with the places they inhabit. The world and human existence are co-constituted, and it is through lived experience that humans come to understand and engage with the world.

Heidegger contends that human beings are 'thrown' into a specific situation or place, a concept that underscores the contingency and unpredictability of human existence. Individuals cannot predetermine their existential circumstances, such as their socio-economic status, cultural background, physical abilities, or intellectual capacities. Rather, they find themselves 'thrown' into a particular world that shapes their experience. Heidegger rejects the Cartesian notion of space and argues that, just as humans and the world are inseparable, so too are humans and the spaces they inhabit. He critiques the idea of an abstract, absolute space, asserting that 'Space by itself is nothing; there is no such thing as absolute space (Heidegger, 1927; Bolak Hisarlıgil, 2007). For Heidegger, space is a site of interaction and experience, and to experience space is to be-in-the-world.

Heidegger distinguished between space and place by stating, "Space consists of linear orientations and measurable, calculable dimensions." In contrast, the concept of place reflects a mode of understanding space through practical knowledge that brings the sense of belonging into consciousness—transcending mere spatiality to grasp its reality. Through this distinction, Heidegger also clarified the difference between "building" and "dwelling". According to him, not every structure constitutes a dwelling, nor does every space necessarily provide a sense of place. Building refers to a more physical condition, akin to space, whereas dwelling, like place, occurs in the realm of thought. For instance, a truck driver may "dwell" on the roads, as they become his home, yet the road itself is not a lived, inhabitable space. Thus, space is a "form," whereas place is a "mode of being" (Tuncer Gürkaş, 2010).

The Norwegian theorist Christian Norberg-Schulz extended Heidegger's ideas into the field of architecture, introducing a new concept: *Genius Loci*—the Spirit of Place. Originally a Roman concept, *Genius Loci* in ancient Roman belief referred to the unique essence and protective spirit inherent in every entity (Koçyiğit, 2007). Schulz argued that places possess a distinct spirit independent of the observer and the meanings people attribute to them. He maintained that each place has an identity, a unique character, and specific qualities that architecture must reveal; otherwise, architecture becomes a meaningless endeavor (Norberg-Schulz, 1968).

According to Schulz, architecture must first immerse users in the conditions and influences of the natural environment. Then, through wholeness and form, it should envelop users freely and without constraint. Finally, the architectural product must respond to the conditions of its surroundings. He emphasized that these elements are essential for creating meaningful places for human beings. Schulz's primary focus in architecture was not only the function of buildings but also the forces that shape them and the meanings they convey (Seçer, 2016).

Building upon Heidegger's philosophy, Schulz highlighted the direct relationship between human existence and architecture. He focused on the meaningful connections between humans and their environment, as well as between architecture and place. He asserted that architecture, as a human-made environment, should be shaped according to the characteristics of its location and should reveal the spirit of that place. Thus, spaces should not be designed as detached, empty volumes in space, independent of their surroundings. In this regard, Schulz also critiqued modern architecture, emphasizing the necessity of revealing the spirit of place and its distinctive features (Norberg-Schulz, 1968; Seçer, 2016).

In his exploration of how a space transforms into a *place*, Schulz argued that the organic connection between space and place originates from *Genius Loci*. He introduced the concept of *lived experience* (*Erlebnis*), which he defined as a behavioral and cognitive schema that shapes human orientation and existence. He distinguished three types of spatial experience: (1) *pragmatic space*, defined by action; (2) *perceptual space*, which generates immediate orientation; and (3) *existential space*, which forms an environmental image (Eyce, 2011).

In the phenomenological studies of the French philosopher Maurice Merleau-Ponty, perception is fundamentally embodied, with a strong emphasis on the concept of embodiment. His philosophy positions the human body as the central subject of the experiential world (Merleau-Ponty, 2005; Sezgin, 2015). While Heidegger conceptualized existence as "being-in-the-world," in Ponty's thought, this notion transforms into "becoming and embodying within the world". This perspective suggests that every encounter with the world involves a process of rediscovery, as if learning anew (Eyce, 2011).

According to Ponty, the individual is both a thinking body and a social being who engages in spatial experiences within daily life. Opposing the Cartesian view that considers space as a geometric extension and reduces individuals to mere users of space, Ponty argues that space cannot be separated from the body and that each person is inherently part of and intertwined with their spatial environment. Subject, object, and world co-constitute one another in a simultaneous and reciprocal interaction. In other words, reality is understood through bodily perception and comes into existence through momentary experience (Merleau-Ponty, 2005; Seçer, 2016). We inhabit space through our bodies, and our connection with the external world is always mediated by the body. Since we are bound to our bodies and cannot detach from them, we are equally dependent on space. Given this interdependent relationship, Merleau-Ponty's assertion that "space is existential, and existence is spatial" holds significant weight. Space enables existence; it is the womb that gives rise to being and provides its foundation. The existence of space is animated by bodily movement and the dual relationship between subject and object. Existence is inherently spatial because there is no being without place. Even in the absence of human life and bodily interactions, spaces persist in their material reality. A bombed-out city in wartime, an abandoned village emptied due to terrorism, an obsolete industrial structure, a deserted house, or a closed shopping mall affected by economic crises—all remain as spatial entities. Although they depend on bodily movement to be fully lived and experienced, their physical existence is independent of human presence. However, the inverse is not true: there is no existence of the body without place (Tuncer Gürkaş & Barkul, 2012).

Ponty's approach presents an integrated relationship between the body, space, and movement, where each concept is explained through the others. In this dynamic interaction, the body acts as the interface that moves and perceives; movement constitutes the act of transition initiated by the body; and space serves as the substrate for movement. Put differently, the body generates movement, movement enables spatial experience, and space, through its physical presence and the movement it accommodates, provides perceptual and experiential data to the body. These data correspond to sensory information that the body receives (Sezgin, 2015). Spatial experience, therefore, is an extension of the perceived world, characterized by a mutually constitutive relationship between the perceiving body and the perceived space (Topal, 2013).

Like Merleau-Ponty, Pallasmaa emphasizes the importance of the cooperation of the senses in perceiving the external world and critiques the privileging of vision over other senses. According to him, architecture is not merely a visual discipline but rather an interplay of multiple sensory experiences that interact and merge with one another (Sezgin, 2015). In his book *The Eyes of the Skin* (2011), Pallasmaa distinguishes between two types of spaces: the optic space, perceived through vision, and the haptic space, experienced through touch. The optic space is shaped by the dominance of vision in modern architecture, where perspective and the privileging of the eye place sight at the center of human perception. In contrast, the haptic space is what truly leads to understanding, activating the world of the senses and fostering an interaction between humans and their environment. According to Pallasmaa, in contemporary society, technology has further reinforced the prioritization of sight and hearing while suppressing the other senses, leading to a lack of bodily experience in architectural spaces. He argues that truly human-centered spaces can only be created by engaging the body as a whole, encompassing all the senses. Criticizing modern design for being predominantly visual, he asserts that it alienates the body—along with its sensory memories and dreams—rendering contemporary architecture devoid of existential and spatial experience (Pallasmaa, 2011). He also differentiates between two modes of vision: focused vision, which is fixated on a single point and aligns with the intellect's notion of the "ideal," and peripheral vision, which encompasses the preconscious field of perception beyond the focused area. It is peripheral vision that envelops the subject in space and enables spatial perception to emerge.

Pallasmaa argues that the reason contemporary cities often feel alienating compared to natural and historical environments, which possess strong sensory qualities, is their lack of engagement with peripheral vision. This perspective concretizes Merleau-Ponty's phenomenological approach to embodied experience within the field of architecture. Our bodies engage with the world through touch, establishing a connection and becoming integrated with it. The essence of space can only be grasped through lived experience; it cannot be predetermined or designed to yield absolute and definitive outcomes (Seçer, 2016).

7. Various Thinkers on Space and Place

7.1. Henry Lefebvre (1901–1991)

A Neo-Marxist existential philosopher, Henry Lefebvre was a sociologist of urban and rural life and a theorist of social space who made significant conceptual contributions to the study of space (Hubbard & Kitchin, 2018). In his most well-known and widely read book, *The Production of Space* (1974), he examines social space as the national and planetary expression of modes of production. Lefebvre's comprehensive and multifaceted spatial theory has provided a crucial foundation for subsequent discussions and studies on space. The concepts of 'spatial periodization' and 'spatial triad' have become two primary elements forming the structural basis of his theory of the production of space.

7.1.1. Spatial Periodization

As an implication of Lefebvre's assertion that "space is a social product," spatial periodization aligns with the periodization of modes of production, a common approach in Marxist theory. According to Lefebvre, each mode of production possesses its own corresponding space, and throughout history, transitions from one mode of production to another have resulted in the creation of new spaces. Based on this idea, Lefebvre discusses absolute space, sacred space, historical space, abstract space, contradictory space, and differential space, thus outlining a brief history of space.

a) Absolute Space: The origins of absolute space, as described by Lefebvre, are rooted in agriculture, encompassing spaces where peasants or nomadic herders worked (Lefebvre, 2014). Primitive communities engaged in hunting or agriculture formed their own social spaces within these environments, which remained in harmony with nature. Due to the strong connection between these spaces and nature, as well as the constraints on human dominance over space, it was not entirely possible to sever these spaces from their natural ties and transform them into built environments (Lefebvre, 2014; Ghulyan, 2017).

b) Sacred Space: Sacred space emerged as absolute space gradually became occupied by political and religious authorities. Parts of nature were sanctified and appropriated by magical and religious power, becoming instruments of political control. Sacred space, although stripped of its natural state, continued to be perceived as part of nature and was both religious and political in nature. These spaces can be considered the initial distinction between the social and natural worlds and the beginning of the differentiation between the center and periphery in social space (Lefebvre, 2014; Ghulyan, 2017).

c) Historical Space: The fragmentation of sacred or absolute space by the so-called 'barbarians' who invaded Rome led to the first major agricultural reform in Europe during the feudal era. The settlement of these groups altered the nature of private property, giving rise to a new spatial production that marked a distinction between public and private domains. Consequently, spaces for accumulation emerged, and cities began to be organized as marketplaces. From the 12th to the 19th century, spaces of accumulation coexisted with spaces of war (Ghulyan, 2017).

d) Abstract Space: With the transition from feudalism to capitalism, nation-states and abstract spaces emerged, shifting the primary agent from the city to the state. Consequently, urbanized space was replaced by state-controlled space. The philosophical foundation of abstract space lies in Cartesian philosophy, which emphasizes the logical and mechanistic analysis of nature and space. Due to its Cartesian influence, abstract space is the realm of white paper, drafting boards, plans, sections, elevations, models, and projections (Lefebvre, 2014; Ghulyan, 2017). This type of space is not inherently abstract but is experienced as abstraction, defined through the perception of an abstract subject.

e) Contradictory Space: Contradictory space is essentially an extension of abstract space, sharing its characteristics. However, due to the latest developments in capitalism, the contradictions inherent in abstract space have deepened further. Thus, abstract space, both quantitatively and qualitatively, now manifests as contradictory space, revealing a more acute and visible series of contradictions than in the past (Lefebvre, 2014; Ghulyan, 2017).

7.1.2. Spatial Triad

Lefebvre analyzed historical spatializations through three axes that maintain a dynamic equilibrium and are dialectically interconnected. He proposed that space is experienced through three fundamental aspects: perceived, conceived, and lived space. In conceptualizing these dimensions, he introduced the triad of spatial practice, representations of space, and representational spaces.

a) Spatial Practice (Perceived Space): According to Lefebvre, a society's spatial practice produces its own space. Spatial practice primarily concerns space as a material reality. It encompasses buildings, structures, workplaces, private and leisure spaces, as well as the networks and routes that connect them. Consequently, it can be empirically observed. Due to its physical nature, it allows for the direct experience of space. In short, perceived space consists of physical spaces that house all daily practices and activities and can be experienced through perception by social actors (Lefebvre, 2014; Ghulyan, 2017).

b) Representations of Space (Conceived Space): This dimension of space is mentally constructed, designed, and related to metaphysics and ideology, often referred to as 'the space of the philosopher.' Conceived space is conceptualized as representations of space, stemming from individuals constructing mental representations of reality and their experiences with space (Fataar & Rinquest, 2019). These spaces are deliberately designed by experts to accommodate specific organizational outcomes (Lefebvre, 2014; Berti et al., 2018; Pawlicka-Deger, 2020).

c) Representational Spaces (Lived Space): The third aspect of Lefebvre's spatial triad comprises spaces occupied by inhabitants and users, which can be altered by ordinary people. These are spaces where spatial arrangements are adapted, modified, or transformed and where bottom-up changes can occur, even if inconsistently. Lived space, known as social space, signifies the lived experience of space—one that is produced and transformed over time through use and is imbued with symbols and meanings (Lefebvre, 2014; Fataar & Rinquest, 2019; Pawlicka-Deger, 2020).

To summarize, within the framework of the spatial triad, there are;

1. A physically produced and utilized form,
2. A mental representation,
3. A simultaneously material and mental lived dimension.

As visualized in Fig. 2, through the dialectical interplay of these elements, space is produced and modified over time (Berti et al., 2018). To simplify these concepts, in everyday social life, perceived space (*le perçu*) consists of ordinary activities and possibilities, yet it is often overlooked within the professionally and theoretically defined conceived spaces (*le conçu*) of cartographers, urban planners, and land speculators. Simultaneously, individuals exist within 'lived space,' which is sustained and accessed through art and literature and shaped by imagination. This type of space has the power to redefine and transcend the balance between perceived and conceived space (Hubbard & Kitchin, 2018).

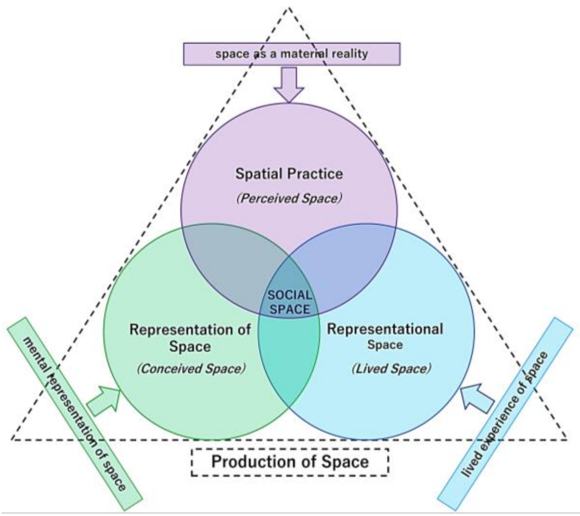

Fig. 2. Henry Lefebvre's triad of space production. (visualized by the authors)

7.2. John A. Agnew (1949 - …)

Like Lefebvre, who provides a rich theoretical framework for understanding how society conceptualizes, produces, and perceives space, political geographer John A. Agnew has defined three fundamental aspects of place:

1) *Place as a location or a site in space:* A settlement or a place where an action (or object) is located and is connected to other locations in space through interaction, movement, and diffusion. According to this definition, all places are distinguished based on their location, and all objects are defined through spatial relationships.

2) *Place as a series of locales or settings:* A place consisting of material environments for social relations, such as a series of neighborhoods, event venues, or contexts where everyday life activities take place. These spaces, which may include workplaces, homes, shopping malls, churches, etc., have a tangible form and encompass both social interactions and concrete behaviors.

3) *Place as a sense of place:* Identification with a place in terms of a unique community, landscape, or moral order. This dimension involves the emotional attachment necessary for settlement and the sense of belonging to a place, which is particularly significant. Here, place is not simplified as a mere material environment but is instead understood as having the power to shape social relationships through complex mechanisms of inclusion and exclusion (Pawlicka-Deger, 2020).

7.3. Marc Augé (1935 – 2023)

French anthropologist Marc Augé introduced the concepts of Anthropological Place, Non-place, and Super modernity in his most famous book, Non-Places: Introduction to an Anthropology of Super modernity, published in English in 1995. In this work, he systematically elaborates on the dimensions of space, place, and non-place, providing a conceptual framework for the anthropological study of spaces, practices, and cultures in contemporary Western society. Augé defines place as localized, occupied, organic, and historical—a space meaningful to visitors where identities can be produced. According to Augé, for an area to become a place, it must be mentally constructed through repeated encounters and complex face-to-face relationships. In essence, place is defined within the axes of identity, relationships, and historicity (Seçer, 2016; Hubbard & Kitchin, 2018).

Augé in this book uses the idea of supermodernity to describe today's world characterized by the three figures of excess; overabundance of events, spatial overabundance, and the individualization of references. Within such a world, there is a widespread transformation of the characteristics of space, time, and place, giving rise to non-places (Augé, 1995). Non-places are empirically measurable spaces that reflect individual experiences and perceptions of places. They lack the qualities of place such as meaning and belonging, having entirely lost their significance. Examples include metro stations, highways, airports, shopping malls, hotels, and holiday resorts—spaces that create their own realities and are generated by circulation, consumption, and communication, categorizing them as non-places. In these spaces, where social interactions are minimal, individual identities are invalidated, and every person is considered part of the crowd. Relationships in these places are defined by alienation, abandonment, and loneliness, and users inhabit these spaces temporarily (Berber, 2011; Hubbard & Kitchin, 2018; Usta, 2020).

Augé's work on non-places, which frequently attracts attention, differs significantly from other studies on the subject conducted by researchers like Edward Relph, who critiques placelessness in the Western world, or Melvin Webber, who examines the role of non-place in the emergence of flexible societies in urban areas. According to Augé, non-places can be comforting for many users due to the familiarity they evoke, yet for some individuals, the experience of these places can evoke a sense of indifference (Hubbard & Kitchin, 2018). Augé expresses that non-places never exist in a pure state, stating, "places continually remake themselves within themselves, their relations being refashioned and sustained within them... places and non-places are like opposite poles, the former never entirely erased and the latter never fully completed" (Auge, 1995; Hubbard & Kitchin, 2018).

7.4. Michel de Certeau (1925–1986)

Michel de Certeau explored everyday practices within the relationship between space and place, focusing on the distinction between the two concepts. In his seminal essay *Walking in the City*, featured in *The Practice of Everyday Life*, he begins by describing the pleasure of viewing Manhattan from the 110th floor of the World Trade Center—observing the whole and reading its order. He then transitions to a critique of urban theory, questioning the subject's position, urban planners' perspectives, the comprehensive control of space, and the claims of social theory, ultimately highlighting the difference between space and place (Hubbard & Kitchin, 2018).

From this example, de Certeau identifies two contrasting perspectives through which a subject might engage with space: one is the panoptic gaze that examines the city from above, while the other consists of the moving bodies observing urban structures from below. The former overlooks the transience of daily life, while the latter remains tied to it (Gelinas-Lemaire, 2018). In other words, de Certeau discusses the city in terms of two opposing figures: the 'walker,' who perceives the city from street level, and the 'voyeur,' who admires the city's overarching structure from above. He uses this dichotomy to explain space and place differences. (Gazzard, 2011).

According to de Certeau, the walker kinetically experiences the city through actions that defy the prescribed behaviors anticipated by cartographers and urban planners. In this sense, space is a practiced place. It consists of familiar "here and there" locations created by historically and culturally embedded practices (Tuncer Gürkaş, 2010). Thus, the city transforms into space through the actions of an individual walking along the geometrically defined streets of a plan (Hubbard & Kitchin, 2018). This perspective reverses the conventional geographic notion that associates space with abstraction and place with lived and experienced forms.

In de Certeau's terminology, space is characterized by mobility and dynamism, while place is described as static and fixed. He defines place as a position on maps and plans, whereas space is a meaningful position shaped by actions. Spaces are the lively streets traversed by people, while places are the buildings and other components of the built environment that define those streets (Tuncer Gürkaş, 2010). For de Certeau, space is produced through actions and defined by experiences, whereas place is a blank template upon which actions occur (Tuncer Gürkaş, 2010; Adıgüzel Özbek, 2016; Usta, 2020).

De Certeau likens the relationship between space and place to that of grammar and speech in language: although every language has a defined grammatical system, there are countless ways to construct meaningful sentences. Thus, if place is the word, space is the speech. Memories, stories, and narratives can transform a place into a space (Adıgüzel Özbek, 2016). De Certeau compares this to a walker's infinite ways of engaging with the street, stating, "A walker does not walk on walls, but the ways they use the street are limitless" (Tuncer Gürkaş, 2010).

8. Conclusion

Throughout history, the concepts of place and space have evolved across different philosophical and architectural traditions, shaping our understanding of how humans interact with their built environments. From Plato's and Aristotle's foundational distinctions to Lefebvre's socio-spatial theories and Merleau-Ponty's phenomenological insights, it is evident that space is not merely an empty container but a lived, experienced, and constructed reality.

In architectural discourse, this realization underscores the necessity of designing spaces that do not solely prioritize physical form but also consider the sensory, emotional, and social dimensions of human experience. The critique of modernist approaches, as articulated by thinkers like Pallasmaa, further emphasizes the importance of embodiment and multi-sensory engagement in creating meaningful places.

Ultimately, this study highlights that the relationship between place, space, and human experience remains central to architectural theory and practice. Recognizing the interplay between perception, movement, and memory within spatial environments challenges architects and theorists to move beyond rigid physical definitions and embrace a more dynamic, human-centered approach to space-making. Future research could explore how contemporary architectural practices integrate these philosophical perspectives to foster more inclusive, engaging, and identity-rich spaces.

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Understanding architectural memory of Milli Reasürans building through cinematographic montage

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Abstract. This study investigates how cinematic montage can be utilized to reinterpret architectural memory, focusing on the Milli Reasürans building in Istanbul.Traditional architectural historiography tends to prioritize technical representations such as plans, sections, and elevations, often neglecting the experiential and temporal layers embedded in buildings. By incorporating cinematic imagery and montage, this research proposes an alternative approach that brings together fragmented memory traces—including archival documents, photographs, oral histories, and personal narratives—to construct a multi-layered spatial reading. The methodology is structured around three phases: collecting memory traces, analyzing representational memory, and reconstructing these fragments through cinematic montage. Informed by Henri Bergson's theories on duration and Gilles Deleuze's concept of the movement-image, alongside architectural and memory studies by Paul Ricoeur, Douwe Draaisma, and Marc Augé, this research examines how cinematic montage can reconfigure architectural narratives. The study engages a broader spectrum of montage strategies to explore the intersection of memory, space, and representation.The Milli Reasürans building is re-imagined as a living archive where the past is constantly reconstructed through the lens of the present, by layering images, textual records and experiential narratives, and by superimposing different fragments of time and memory. This approach not only challenges linear, chronological understandings of architectural history but also highlights how montage techniques can offer richer, multi-layered interpretations of space and memory. In conclusion, the study demonstrates that buildings, through cinematographic montage, have temporal and spatial narratives that extend beyond their physical boundaries, offering new possibilities for representing and understanding the role of architecture in urban memory.

Keywords: Milli Reasürans; cinematic imagery; memory; montage; architectural historiography.

1. Introduction

Architectural historiography often addresses structures through conventional representation tools such as plans, sections and facade drawings. These representations may be functional for documenting the physical characteristics of the structure; however, they carry the risk of ignoring the temporal layers of the space, its experiential traces and the connections it establishes with the user. In this context, the existence of structures within the city includes not only physical but also social, emotional and memoryl layers. In this study, a new approach to architectural historiography is proposed through the concepts of cinematographic image and montage. Cinematographic montage disrupts the sequence of fragmented images formed over time and allows them to be re-interpreted. In this context, it is possible to reconstruct the memory of a structure through interrupted narratives, experiences and representations.

The study takes the Milli Reasürans building, built in the mid-1980s, as a case study. The architectural characteristics of the building, its relationship with the city, the competition process and subsequent uses show that it is not only a physical object; it is also a living carrier of memory. Reading this structure through cinematographic montage aims to reveal temporal ruptures and traces of memory. Thus, a non-linear, layered and experiential architectural history writing is proposed. In this paper, the memory of Milli Reasürans will be examined with a three-stage analysis framework: Memory, Memory of Representation and Representation of Memory. Each title will discuss how we can transform the historical and spatial memory of the structure through cinematographic imagery and montage.

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2. Conceptual Framework: Cinematographic Image and Montage

The cinematographic image is not limited to the visual aesthetics or composition of cinema frames within a film. This concept gains depth especially with Gilles Deleuze's "movement-image" and "time-image" theories. According to Deleuze, cinema does not only present momentary sections of movement; it conveys movement itself through images (Deleuze, 1983). In this way, images turn into narratives that carry the continuity and variability of space. Time-image can show the past, present and future simultaneously within the memory of a structure, especially by breaking the cause-effect relationship. At this point, the cinematographic image comes into play as a powerful tool to make the temporality of architectural representations visible.

Cinematographic montage determines the way these images are brought together. The understanding of montage theorized by Sergei Eisenstein has the capacity to produce new meanings through collisions arising from the juxtaposition of different images. Eisenstein's sub-genres such as "intellectual montage", "rhythmic montage", "tonal montage" and "metaphorical montage" can be read not only in cinema but also in architecture. When the plans of a building spread over time, user stories, archive documents and current images are brought together with these montage techniques, new meanings about the memory of the structure can emerge (Eisenstein, 2014).

The method used in this paper enables the production of cinematographic images by rethinking the different forms of montage in the context of architecture. While intellectual montage establishes the intellectual relationship of documents from different periods, rhythmic montage analyzes the temporal flow of circulation in the building. Tonal montage emphasizes the emotional effect of space through the relations of material, light and void. Speculative montage produces alternative memories of the structure with non-archival but fictional images.

Thanks to this theoretical framework, it becomes possible to address architectural representation not only visually or physically, but also with its temporal, intellectual and emotional layers. The Milli Reasürans building is at the center of the study as an architectural memory object that is both documented and reconstructed in line with this approach.

3. Historical Layers of the Building: Competition, Construction and Usage Process

Milli Reasürans T.A.Ş. General Directorate Building and Complex which was opened for use in 1995, is a structure with a strong public aspect. Its architects are Sevinç Hadi and Şandor Hadi Located at the intersection of Teşvikiye and Maçka Streets, the building is positioned between two important historical structures: Maçka Palas and Ralli Apartment. It also establishes a strong relationship with Abdi İpekçi Street. The rows of exhibitions and shops on the ground floor of the building serve as a passage connecting two different streets of the city. The 45-meter bridge facing Maçka Street, which is the iconic facade of the building, leaves a strong mark on urban memory; it both creates a response to Maçka Palas and gives the building a monumental appearance with the space left in the form of an iwan.

In 1984, Milli Reasürans T.A.Ş. organized a national architectural project competition by invitation for the new headquarters building (Dündaralp, 2011). The competition title envisaged not only meeting the need for offices but also producing a modern and permanent structure that reflected the prestige of the institution. 15 offices were invited and 9 of them submitted their projects. Sevinç Hadi and Şandor Hadi's project was selected as the winner in the competition, and only an honorable mention was given because the other projects did not offer a viable alternative. The jury reports emphasize that the Hadi couple's proposal fully complied with the specifications and was highly applicable.

The project area contains important reference points in terms of both architectural and urban context. Structures such as Maçka Palas and Ralli Apartment were decisive in the formation of design decisions; especially the iwan solution spatially expressed the relationship established with these structures. The iwan not only provides urban continuity and permeability, but also strengthens the monumentality of the structure. As Sevinç Hadi emphasizes in her own narratives, this decision is both a solution to mass fears and the product of an approach sensitive to the historical environment.

The history of the structure should be considered by dividing it into three main periods: the competition and design process (1984–1985), the construction process (1988–1992) and the usage period (Dündaralp, 2011). The evaluation criteria of the jury during the competition process included criteria such as land and environmental conditions, harmony with historical structures, elevation differences, placement of program components with symbolic value and technical feasibility. The presence of the structure in Maçka should be evaluated as a reflection of the transformation in Turkish architecture in the 1980s. This period is the years when architecture was considered not only as a physical production but also as a tool of image, identity and representation.

The passage program added to the design reinforced the structure's place in the collective memory. Programs such as restaurants, bookstores, exhibitions, cinemas and bars strengthened the structure's relationship with public life and made it not only an institutional center but also an urban meeting place. Despite its relocation to Levent, the Milli Reasürans Passage continues to be in public use today. This continuity is an important layer that preserves the memory of the structure.

The structure is built on a 34,000 m² development right and is divided into three main sections: the general directorate, auxiliary facilities and general service sections. Design decisions were shaped by both the technological possibilities of the period and the relations established with the urban texture (TRT 2, 2024). The parking system, which goes down to four floors underground, draws attention in terms of construction technology and also makes an indirect contribution to the foundations of the surrounding historical structures with the anchor system. The cinematographic images and montage representations to be produced regarding the structure will be fed by these historical layers and the urban context. The next section will discuss how this historical background can be reconstructed through images.

3. Reconstructing Milli Reasürans with Cinematographic Montage

The Milli Reasürans building, beyond being just a physical structure, requires a cinematographic reading with its spatial structure that offers transitions between different levels, passages where interior and exterior spaces are intertwined, and its dynamic relationship with public spaces. In traditional architectural historiography, structures described through plans, sections, and facades may be insufficient to reflect such multi-layered spatial experiences. Therefore, a cinematographic image approach is necessary to make sense of Milli Reasürans' traces in memory, its spatial changes, and its interaction with its users. The building's passage (that includes stores and restaurants), exhibition areas, inner courtyard, and its relationship with public spaces at different scales cannot be read from a specific perspective; they can only be made visible with cinematographic techniques that intertwine multiple perspectives. Unlike plans and sections, the cinematographic image offers a new perspective to architectural historiography by addressing the structure through changes in movement, time, and perception. In this context, Milli Reasürans is not only evaluated as a static structure, but as a living organism that includes different user experiences and layers of memory.

Cinematographic montage has a methodological basis based on how different types of montage (intellectual montage, tonal montage, rhythmic montage, speculative montage) can be transferred to architectural representation, based on the theoretical framework developed by Eisenstein. This approach enables not only the reproduction of physical space, but also the reinterpretation of the relationship established with the past of the structure and the traces it leaves in the urban and user memory. In this context, montage is not only a method of establishing a narrative, but also a tool that multiplies temporality, emphasizes the transition between spaces, and produces new meanings by bringing together representations from different periods. In the case of the Milli Reasürans structure, this montage method allows the superimposition of the phases the structure has gone through, different user practices, and urban context to be read.

Within the scope of this study, the Milli Reasürans building was studied through 3 cinematographic montages.

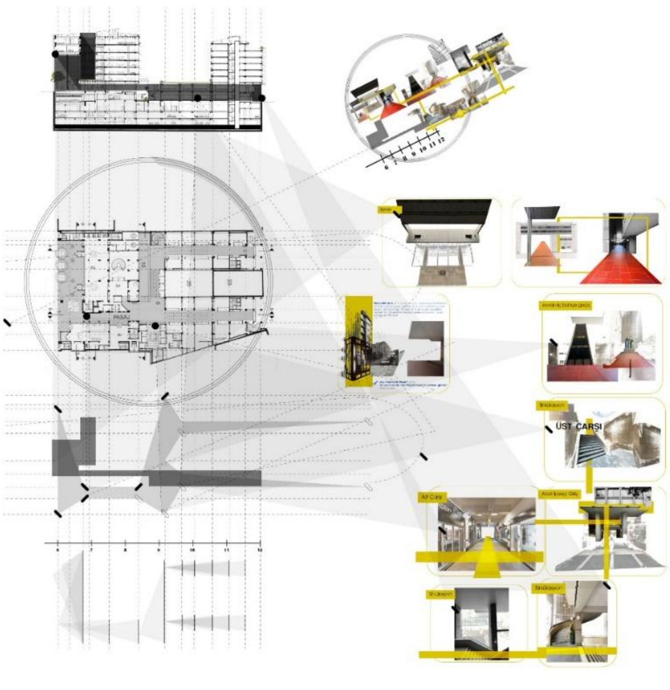

Fig. 2. Rhythmic Montage

In the first image study, the passage starting from the iwan of the building towards Teşvikiye and reaching Abdi İpekçi Street was traced through sections and plans. In this study, which is based on the experience of space and the imagery of perception, a multi-layered and duration-based canvas was created by presenting a path through the user's perception of space. Focusing on the relationship of the building with the public space, the movement/space inventory of the building was made both as a whole and as a fragment, within the boundaries of the private/public distinction. The representation of temporal experiences such as circulation, transition between levels, light and shadow in the interior spaces of the building was created with rhythmic montage.

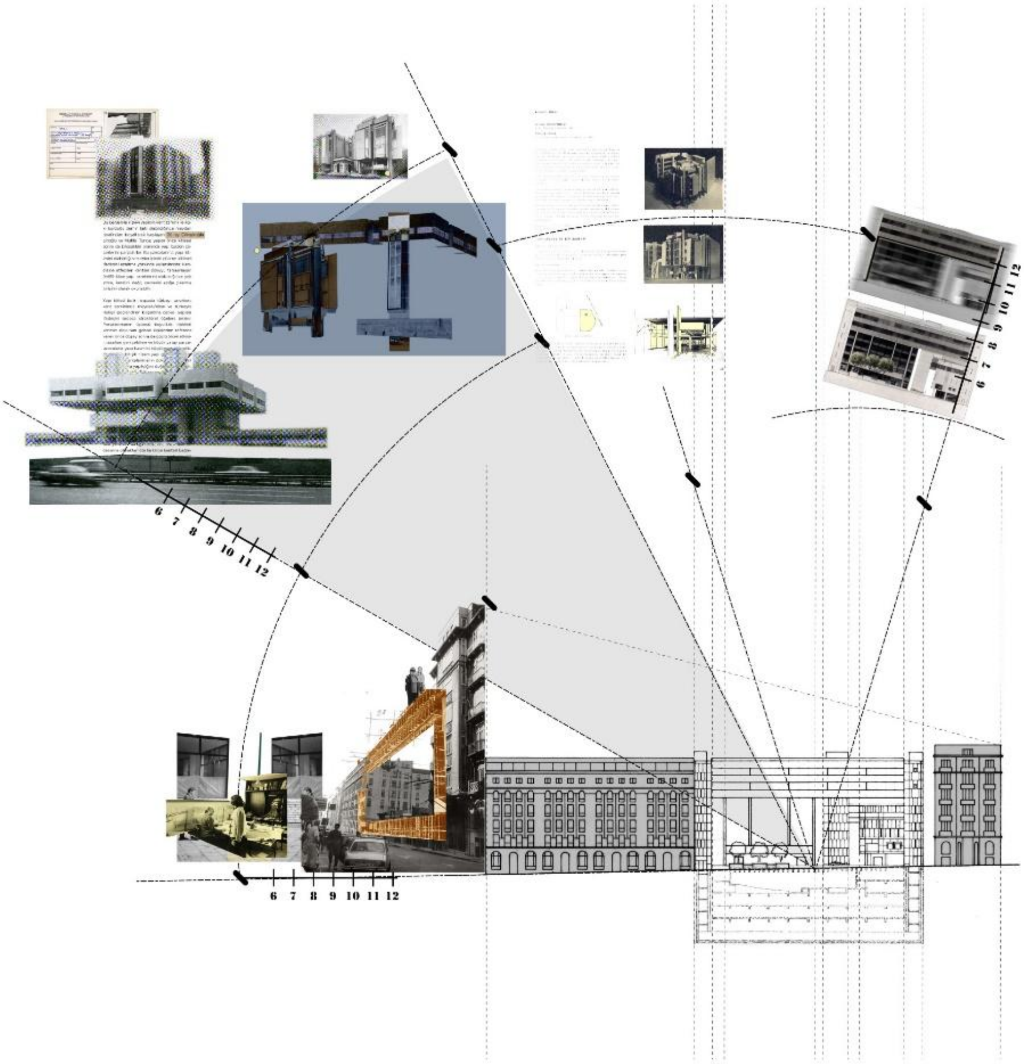

Fig. 3. Intellectual Montage

The second image study is based on the question "What is the building a plural of?" and explores the relationship of the structure with Maçka Palas and Ralli Apartment, as well as how these neighboring buildings influenced the architectural decisions made for Milli Reasürans, especially in terms of its facade design. Furthermore, the image juxtaposes Milli Reasürans with other buildings from different spatial and temporal contexts that, at first glance, seem unrelated. This connection is established through a metaphorical/intellectual montage. The image also illustrates how Sevinç Hadi and Şandor Hadi, who won second place in the Istanbul Reklam Sitesi architectural competition, later transferred the spatial strategies of the winning project by Günay Çilingiroğlu into the design of Milli Reasürans. In particular, the decision to position the executive offices on the upper level in the competition project is echoed in Milli Reasürans, where both the form and the functional organization reflect a similar hierarchy (Mimarlık Dergisi, 1969).

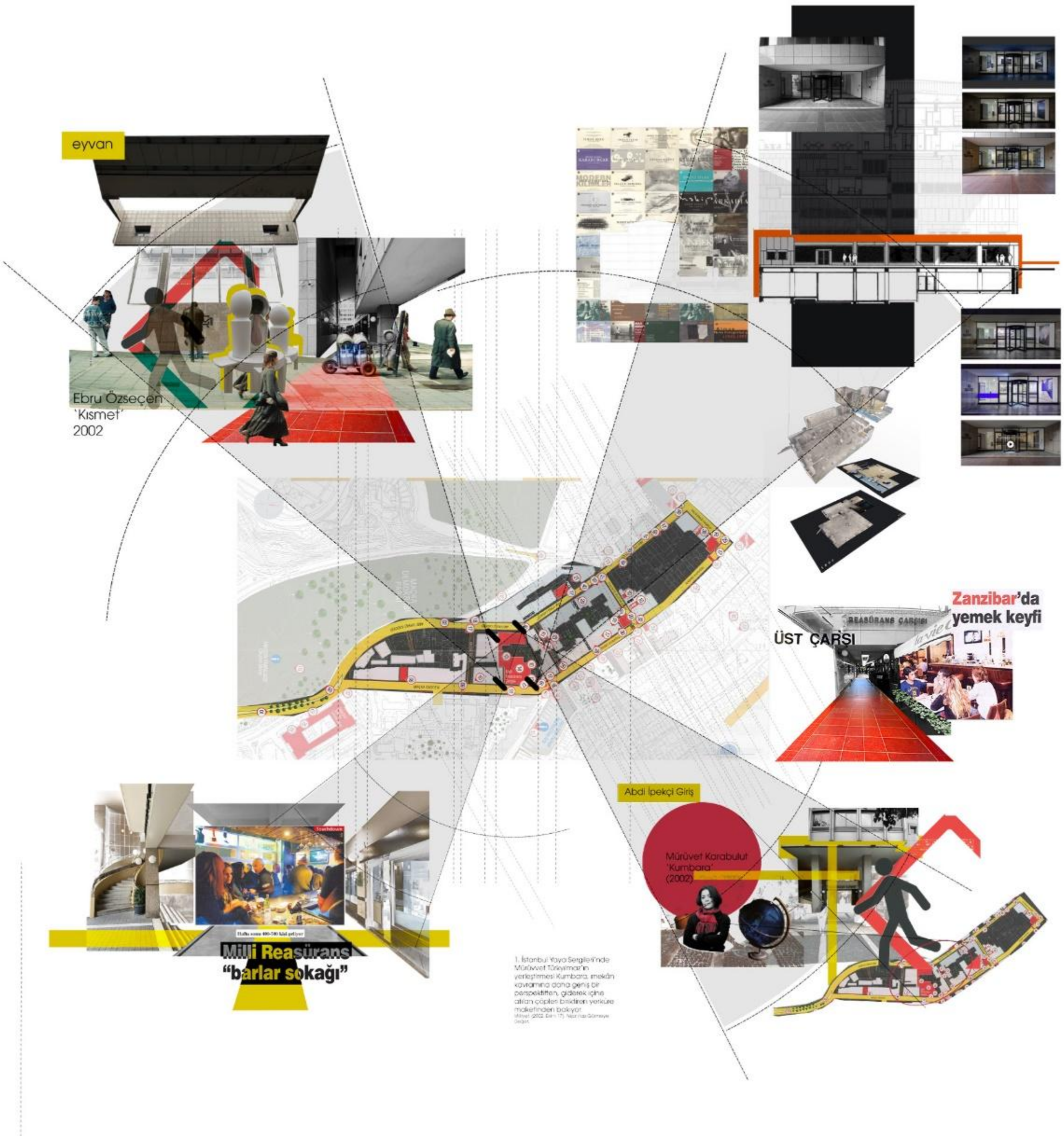

Fig. 4. Overtonal Montage

As the third image, an overtonal montage was used to create a multi-layered narrative by superimposing different levels of meaning through the combination of rhythmic, tonal, and intellectual montage techniques. This approach aimed to simultaneously represent the spatial, historical, and emotional layers of the Milli Reasürans building, revealing aspects of the structure that have been forgotten or overlooked in conventional architectural historiography. Within this framework, the memory of the ongoing exhibition tradition since 1995 is visualized, along with an imagined extension of the works displayed in the 2002 1st Istanbul Pedestrian Exhibition, which took place in Nişantaşı, into the Milli Reasürans context (İstanbul Yaya Sergileri, 2002). Additionally, former restaurants that once operated in the building, reflected in newspapers and magazines but now closed, are reimagined as part of the building's evolving and layered memory (Milliyet, 2002).

4. Conclusions

This study investigated the potential of cinematographic montage as a methodological tool for interpreting the architectural memory of the Milli Reasürans building. The aim was to go beyond conventional representational frameworks and to develop a more layered, experiential, and temporally nuanced understanding of architecture. Through archival research, spatial analysis, and visual montage practices, the study provided a non-linear reading of the building that foregrounds memory, perception, and temporality.

- The use of cinematic montage enabled a rethinking of architectural historiography by highlighting the temporal ruptures and spatial transformations of the building over time.

- Rhythmic, intellectual, and overtonal montage strategies provided multiple layers of representation, allowing the reconstruction of both physical and emotional aspects of the building's memory.
- The case study of Milli Reasürans demonstrated that architectural memory is not static but continuously shaped by the structure's engagement with its users, the city, and its historical context.
- The montage-based visual representations revealed overlooked narratives, such as the evolution of public uses within the building and its symbolic connection to adjacent urban elements like Maçka Palas and Ralli Apartment.
- Ultimately, this approach contributes to architectural theory by expanding the possibilities of how buildings are read, remembered, and represented, suggesting that cinematographic montage can serve both analytical and creative functions in contemporary architectural historiography.

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Analysis of Van Pier and Tatvan Pier at the intersection of railway and sea routes

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Abstract. Van Pier has been an important maritime transportation point since the pre-Republican period. For many years, it has been the most important transportation point to reach Van city center. Since 1971, the trains coming from Tatvan Pier, the opposite shore of the lake, have started to be transported to Van Pier by ferry. The trains coming from the west of the Anatolia, disembark their passengers at the Tatvan Station. The trains cross Lake Van without passengers, and they are transferred from Van Pier to the railway only as freight trains. The transportation continues by rail and reaches Van Station. They take their passengers again at Van Station and continue their Asian voyage through Iran. This is a significant railway route opening to abroad from Anatolia to Central Asia. This railway route is significant as the modernised continuation of the historical Silk Road route. Moreover, Tatvan Pier and Van Pier is one of the unique examples in terms of providing land connection of railway vehicles over the lake. This study aims to examine the development of this railway and maritime transportation with its vehicles and structures, with the focus on Van Pier and Tatvan Pier. The research study is based on the review of relevant literature and analysis of old archival data from the architects' perspectives and field observations. This study might shed light on architectural history and transportation structures.

Keywords: Van Pier; Tatvan Pier; Transportation structres; Railway; Sea route

1. Introduction

Railway transportation and sea transportation are interdisciplinary research subjects in which lots of disciplines, such as mechanical engineering, civil engineering, architecture, urban planning, etc., are interested with. Turkey has a significant railway routes between Europe and Asia. These railway routes are interrupted in two marine points: Bosphorus in İstanbul and Lake Van in Van. The intersection of railway transportation and sea transportation is a significant subject needed to be documented and analysed in the architects' point of view. This study focuses on Lake Van and aims to examine the development of this railway and maritime transportation with its vehicles and structures. This study might shed light on architectural history and transportation structures.

2. Materials ans methods

The research study is based on the review of relevant literature and analysis of old archival data from the architects' perspectives and site observations. The reviewed literature is mostly related to the history of railway transportation, marine transportation, Van Lake, Tatvan and Van. Tatvan Train Station, Tatvan Pier, Van Pier and Van Train Station were analysed on site.

3. History of train ferry and sea transportation in Lake Van

The signifact international railway route of Turkey starts from Edirne Train Sataion and ends with Van Train Station. It connects Europe to Asia as parallel to the historical silk road, which was economical bridge between continentals. However, on this route, there are two significant marine points, in which rail system has no land connections. The trains started to pass he Bosphorous in İstanbul by sea vehicles in 1926. It is said that the early sea vessels used for this were like simple rafts. The first modern train ferry started to be used in Istanbul in 1958. Similarly, the trains started to be pass Lake Van with train ferries after 1971 (
Fig. 1,

Fig. *2* and Fig. 3).

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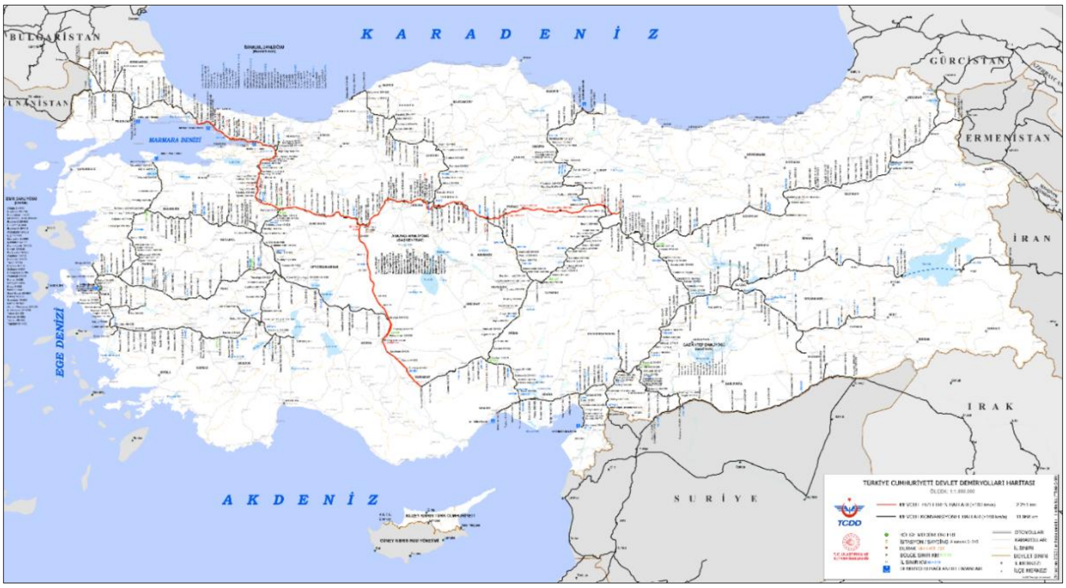

Fig. 1. Railway map of Turkey (TCDD, 2025)

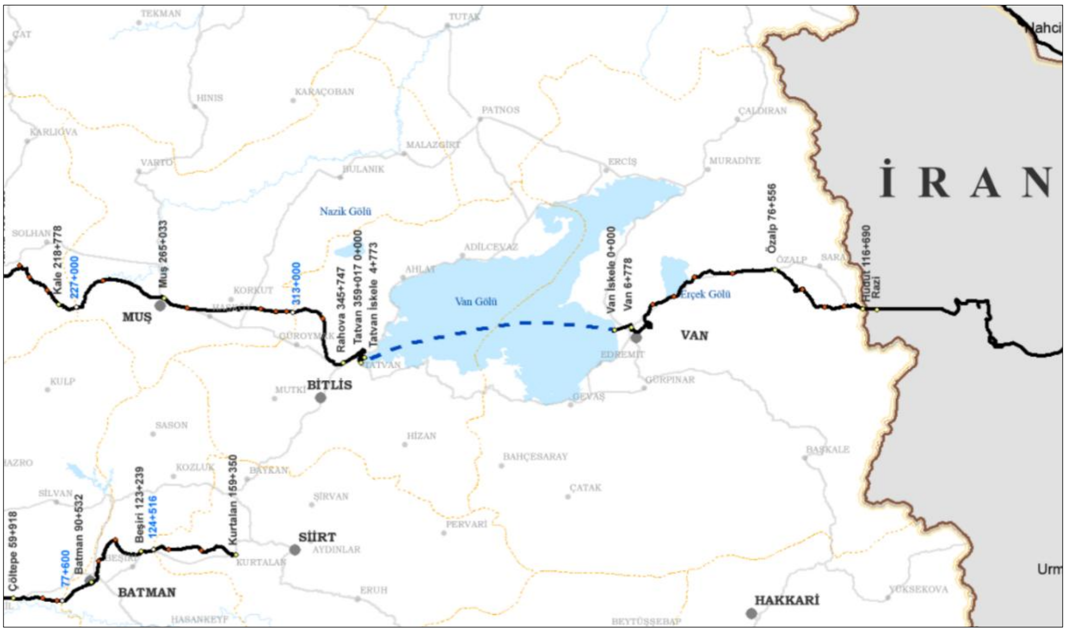

Fig. 2 Railway map of Turkey, a close view of Lake Van and surroundings (TCDD, 2025a)

Fig. 3 GoogleEarth map of Lake Van. Van Pier and Tatvan Pier are marked by the authors.

In the 1800s, transportation services in Bosphorus were supported by simple boats of *Tersane-i Amire*. In 1954, *Şirket-i Hayriye*, the first domestic company to transport passengers, was established. Hüseyin Haki Efendi was the innovative manager of the company and spent his years on thinking how to facilitate the transportation of vehicles in the Bosphorus. Finally, he asked Mehmet Usta, the architect of the company, to develop the idea. As a result of one-year work together, they designed the "*Suhulet*" and constructed it in UK Shipyard. "*Suhulet*" started to be used in Istanbul in 1871. It was also considered as the first car ferry in the world (Raily News, 2015).

"*Suhulet*" was 45.7 meters long and had 450 weighing gross ton. It served for the transportation of vehicles in the Bosphorus. After 1926, the trains also started to pass the Bosphorous. The first modern train ferry, called "*Demiryolu I*", started to be used in Istanbul in 1958. In 1966, the second train ferry, "*Demiryolu II*" was constructed. On those days, the constuction of railway route to Van was not comleted yet. The first train came to Tatvan Train Station in 1965. Van Train Station started to be activated in 1971 (Ayaz & Özyıldıran, 2023). The first trains passed the Lake Van via train ferry called "*Orhan Atliman*" in 1971. Hence, non-stop railway transportation from Europe to Asia started in Van in 1971. Table 1 illustrates all the train ferries constructed between the years of 1958 and 2007. There were seven train ferries, the three of them, called *Demiryolu I, II* and *III* were for Bosphorous, and other four were for Lake Van. The train ferry services from Sirkeci to Haydarpaşa were stopped in 2013, after the construction Marmaray, the tunnel under sea (Kukul, 2020). In current time, only two train ferries were servicing in Lake Van. They are called "*Sultan Alpaslan*" and "*İdris-i Bitlisi*" (table 2) (Ertek, 2025). Two of them can serve better than the total of the old ones. They are considered as the biggest ferries in Turkey (T.C. Tatvan Kaymakamlığı, 2025).

Table 1. Train Ferries constructed from 1958 to 2007 (Kent ve Demiryolu, 2007)

Name	Weight	Lenght	Shipyard	Year
Demiryolu I*	1422 gross ton	72,45 m	Haliç Shipyard	1958
Demiryolu II*	1233 gross ton	72,45 m	Haliç Shipyard	1966
Orhan Atliman	1918 gross ton	81,85 m	Haliç Shipyard	1971
Rafet Ünal	1918 gross ton	81,85 m	Haliç Shipyard	1972
Tatvan	1766 gross ton	81,84 m	Haliç Shipyard	1975
Van	1777 gross ton	81,84 m	Haliç Shipyard	1976
Demiryolu III*	1232 gross ton	72,45 m	Haliç Shipyard	1978

*Demiryolu I, II and III were constructed for İstanbul, and the other four ferries were constructed for Lake Van.

Table 2. Train Ferries constructed from 2015 to 2025 (TCDD Van Gölü Feribot Müdürlüğü, 2025)

Name	Weight	Lenght	Shipyard	Year
Sultan Alpaslan	6921 gross ton	135,66 m	İstanbul&Tatvan	2015
İdris-i Bitlisi	6921 gross ton	135,66 m	İstanbul&Tatvan	2018

4. Tatvan pier

Tatvan Pier has a significant role in sea transportation since the Ottoman period. Since the Lake Van is surrounded by high mountains, such as Artos in the south, Nemrut in the west, Süphan in the north, it is not possible to maintain the railway all the way around the lake. Hence, the main transportation way to Van city center had been over the Lake until 1960s. During the Ottoman eastern campaigns, the army passed by ships departing from Tatvan. When soldiers were sent to Korea in 1950s, they were transported by ships departing from Tatvan (Demirtaş & Subaşı, 2015).

During the Russian occupation of 1915-1918, a shipyard was built by the Russians in Ernis, in the north side of Lake Van. In 1926, this shipyard was transformed into the "*Van Gölü Seyr-ü Sefain İdaresi*". In 1936, it moved from Ernis to Tatvan and named "*Van Gölü İşletmesi*". In Tatvan, besides the pier, a shipyard, lodgings and a hotel were built. "*Van Gölü İşletmesi*" has a significant role in the economic and cultural development of Tatvan.

After "Van Train Station" and the railways route to İran were constructed in 1971, the railway transportation is also preferred to be continued over the lake by the train ferries. It is the most safe and economic way in the surrounding of Lake Van. However, the trains continue only with cargos, since the loads are heavy and the Lake transportation is very slow. All the passengers left the train in Tatvan Train Station. If the passangers want to continue their journey to Iran, they have to pass the Lake Van via highway and get on the train at the Van Railway Station. Fig. 4 illustrates current view of Tatvan city center together with Tatvan Railway Station and Tatvan Pier. Fig. 5 illustrates Tatvan Pier in more close view and

Fig. *6* illustrates the train ferries. Over time, there have been demolitions, transformations and additions to the old buildings of the facility.

Fig. 4 GoogleEarth map of Tatvan. Tatvan Train Station and Tatvan Pier are marked by the authors.

Fig. 5 GoogleEarth map of Tatvan Pier. Structures are labelled by the authors.

Fig. 6 Tatvan Pier and the train ferries (TRT, 2023).

5. Van Pier

One of the two significant piers of Lake Van is Van Pier. It is very close to the Van Citadel, which was traced back to the Urartu Civilisation from the ancient times. In current time, the pier is the starting point of "*İskele Caddesi* (Pier Street)" which was the longest lineer street in Turkey and it is said that it is the second longest street in the World. Hence the position of the pier is very strategic in the urban plan of Van.

"Van Ferit Melen Airport" was constructed in 1943. However, airway transportation was very expensive until the foundation of Anadoljet in 2008. The construction of the regular highway, surrounding the Lake Van, to the city center lasted until the 1960s. Until 1960s, the main transportation of the city center was sea transportation over the lake.

In 1971, Van Train Station was opened and train transportation started from Van to İran as an opening to Asia (

Fig. *7*). At the same time, train ferry services started from Tatvan Pier to Van Pier (

Fig. *8*). Thus, an uninterrupted train service from Europe to Asia was provided. Similar to Tatvan, trains came from Van Pier to Van Train Station without passengers, only with cargos. All the passenger get on the train at the train station. The passengers coming from the east also get off the train in Van Train Station. If they want to contionue to the west via railway, first they have to go through highway and get on the train in Tatvan Train Station. These problem can be solved in the future when the train ferries can be faster and more developed.

Fig. 7 GoogleEarth map of Van city center. VanTrain Station and Van Pier are marked by the authors.

Fig. 8 GoogleEarth map of Van Pier. Structures are labelled by the authors.

7. Results and discussion

The findings of this study reveal the unique character of the Van-Tatvan railway-sea intersection in the context of transportation history of Turkey. Unlike other parts of the railway network, the Lake Van crossing offers a distinctive model that combines railway, maritime and architectural components. The two piers - Tatvan and Van - were constructed not only as transport nodes but also as complex facilities integrating administrative, residential, and industrial elements. Archival data, literature reviews, and on-site observations demonstrate that the Van Lake crossing has played a significant role in maintaining uninterrupted railway connections between Europe and Asia since 1971. Although the ferries currently carry only freight wagons due to time and cost limitations, the infrastructure continues to serve as a strategic asset. Moreover, the train ferries "Sultan Alparslan" and "İdris-i Bitlisi" represent modern improvements in Turkey's maritime freight capacity. However, the full potential of the pier infrastructure is yet to be explored, especially in terms of passenger transportation and urban integration.

8. Conclusion

This study examined the architectural and infrastructural significance of Tatvan and Van Piers, focusing on their historical development and current function within the railway-sea-rail transportation corridor. The study underlines the need to document and preserve such hybrid transportation structures as part of Turkey's architectural and engineering heritage. The case of Van Lake presents a rare example of inland maritime railway connectivity, which could inspire similar integrated systems in other topographically challenging regions. Improving ferry speed and capacity, as well as reintroducing passenger services, could enhance the continuity and efficiency of East-West.

Acknowledgments

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From theory to practice: Bridging cognitive and psychomotor domains in descriptive geometry

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Abstract. The development of Descriptive Geometry (DG) by Gaspard Monge facilitated the separation between design and construction processes by enabling the precise transposition of conceptual designs into tangible forms. As a result, DG remains a core subject in courses like Engineering and Architecture, fostering logical and spatial reasoning alongside drafting skills. Historically, DG education combined theoretical and practical activities; however, it gradually evolved into a more abstract and axiomatic discipline, often neglecting psychomotor skill development. Research highlights that DG curricula frequently emphasise cognitive objectives, assuming students already possess the requisite psychomotor skills for handling drawing instruments. The taxonomy proposed by Simpson categorises psychomotor objectives into stages such as perception, preparation, guided response, mechanism, complex response, and adaptation/creation. These stages underscore the importance of practical engagement in DG learning. Integrated Thematic Instruction (ITI) and Design-Based Learning (DBL) approaches have proven effective in enhancing student engagement and learning outcomes. ITI prioritises thematic relevance, varied activities, and authentic assessment, while DBL promotes hands-on, collaborative problem-solving tied to professional practice. HyperCAL^{3D}, a 3D modelling software designed to support the DG teaching-learning process, complements these methodologies by providing tools for creating and visualising DG activities. This platform supports practical learning through geometric designs, reinforcing psychomotor and cognitive skills. Since its systematic implementation at the Federal University of Rio Grande do Sul (UFRGS) has facilitated the integration of theory and practice in DG activities, offering students meaningful learning experiences.

Keywords: Descriptive Geometry; Design-Based Learning; Integrated Thematic Instruction; Spatial Reasoning; HyperCAL^{3D}.

1. Introduction

The development of Descriptive Geometry (DG) by Gaspard Monge can be regarded as one of the factors responsible for the separation between design and construction/manufacturing processes, as it precisely and rigorously enabled the accurate translation of the designer's envisioned object into a tangible form (Perez-Gomes & Pelletier, 2000 apud Gani, 2016). Consequently, undergraduate programmes that place design at their core, such as Industrial Design, Engineering, and Architecture, include DG in their curricula, as its study enhances the development of logical and spatial reasoning and establishes the foundations for technical drawing representation (Teixeira et al., 2015).

The teaching of DG, as conceived by Monge, envisaged that students would learn the general methods within the first two months of the course, dedicating the remainder of the year to the practical application of knowledge through construction activities such as stone and wood cutting, determination of projected shadows, and the elaboration of perspectives, among others (Monge apud Gani, 2016). Over time, however, as DG evolved into an autonomous discipline, it detached itself from the activities to which it was originally linked, and its teaching transformed into an "abstract instruction" (Gani, 2016, p. 2), based on axiomatic methods (Silva, 2005; Teixeira et al., 2015) and more focused on rules and conventions than on autonomous reasoning (Montenegro, 2005)

Despite this distancing, DG remains a theoretical and practical discipline and, as such, its teaching/learning process should be conducted not solely through cognitive domain objectives — knowledge, comprehension, application, analysis, synthesis, and evaluation (Bloom et al., 1974) — as typically occurs in lecture-based classes, but also through the psychomotor domain. Approaches that fail to consider the development of psychomotor skills often allocate little or no time to the practical component, which is fundamental in any graphic expression discipline.

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An analysis of DG teaching plans applied in the Engineering programmes at the Federal University of Rio Grande do Sul (UFRGS) highlights that the objectives set are predominantly cognitive, assuming that students already possess the psychomotor skills required to handle drawing instruments (Silva, 2005).

According to Krathwohl et al. (1964, apud Simpson, 1966, p.17), psychomotor objectives are those that "emphasise muscular or motor skills, manipulation of materials and objects, or activities that require neuromuscular coordination." Several authors have organised these objectives into taxonomies, hierarchically structured in a similar way to Bloom et al., (1974) regarding the cognitive and affective domains: Krathwohl et al. (1964 apud Simpson, 1966), Simpson (1966), Dave (1970), Harrow (1972), Ferris & Aziz (2005), Hill et al., (2018). Among the various taxonomies, that proposed by Simpson (1966) proved the most suitable for the present work.

The categories of Simpson's psychomotor domain taxonomy are:

- **Perception** – recognition of elements through the senses and the organisation of sensory stimuli in the interpretation of situations for undertaking motor actions;
- **Set** – preparatory adjustments, states of readiness, for carrying out an action;
- **Guided response** – development of basic skills that constitute more complex skills, often involving imitation and trial-and-error processes;
- **Mechanism** – naturalisation and standardisation of sets of skills through increased confidence and performance;
- **Complex overt response** – execution of complex motor actions following the mastery and standardisation of simple actions, characterised by efficiency and fluidity;
- **Adaptation/origination** – ability to adapt actions to different contexts or varying requirements.

These psychomotor objectives not only underpin the practice of technical drawing, but are also crucial in developing practical skills for handling tools and executing precise geometric operations—skills essential for training future professionals in the fields of Engineering, Architecture, and Industrial Design.

Although DG encompasses a dense theoretical component requiring high levels of abstraction, it demands learning experiences that simultaneously develop or refine hand-instrumented drawing skills while striving to achieve cognitive objectives. In order to attain learning objectives across different domains simultaneously, Beatty (2009) suggests Theme-Based Instruction, or Integrated Thematic Instruction (ITI), an approach to facilitate learning by involving various domains in support of a unified theme.

In ITI, key values include: the relevance of learning to students' lives, the relationships among domains, real-world application, appeal and effectiveness (rather than efficiency), activities linked to a unified theme, varied resources and activities, flexibility, and, on the part of the lecturers, a willingness to relinquish some elements of direct control (Beatty, 2009).

In tandem with these methodological principles and to reduce the level of abstraction, previous studies conducted at UFRGS have shown that the integration of DBL with DG not only increased student engagement but also led to a significant improvement in the understanding of descriptive geometry concepts, as evidenced by higher performance in both practical and theoretical assessments (Teixeira et al., 2006), yielding positive results in terms of student engagement and learning (Teixeira et al., 2010, 2015; Bruno et al., 2019).

Design-Based Learning (DBL) is an educational strategy grounded in the active participation of students in design processes, fostering meaningful learning and the collaborative construction of knowledge. DBL is based on the principles of constructivism (Piaget, 2013), constructionism (Papert, 2020), and experiential learning theory (Kolb, 2014), and is implemented through practical projects developed via the integration of multiple disciplines and the creation of innovative solutions.

In the context of DG, DBL emerges as a relevant approach and an opportunity to address the challenges posed by the predominantly abstract nature of the discipline. Spatial representation, orthographic views, auxiliary views, and descriptive operations can be worked on in a practical, more concrete, visual, and interactive context.

Thus, activities may include geometric designs involving three-dimensional objects related to real-world forms, where students create physical or digital artefacts that meet specific geometric and dimensional requirements and constraints. Another focus may involve solving applied spatial problems related to form and position, such as the development of mechanical or architectural components. Furthermore, the use of tools such as interactive graphic software, allowing the exploration of concepts such as projection, auxiliary views, sections, and intersections, assists in the understanding of DG concepts within the practical context of design activities. Other possible applications include the creation of visual materials and simulations to represent descriptive geometric operations.

The principal aim of DBL is to motivate students to collectively apply knowledge and skills in activities related to their future professional practice, highlighting six features: professionalisation, activation, cooperation, authenticity, creativity, integration, and multidisciplinarity (Wijnen, 2000).

Among the reasons for the adoption of DBL at Technische Universiteit Eindhoven (Eindhoven University of Technology – TUE), Wijnen (2000, p.8) emphasises "improving the quality of education, increasing the level of competency orientation, strengthening the coherence between education and research [...]", with the ultimate goal of training engineers capable of delivering better products and innovative systems to society. Furthermore, project-based activities involve reflection-in-action, wherein students are confronted with a system of constantly evolving implications — consequences of their choices and attitudes throughout the process (Schön, 2000).

Nevertheless, designing activities that incorporate features of both DBL and ITI requires considerable planning time on the part of the instructors, as the object must be carefully selected to provide opportunities for advanced editing as well as visualisation operations involving descriptive methods. This stage must also consider the use of the same object across multiple sessions, each covering a different part of the discipline.

For students, such activities must be made available in a manner that allows them to be completed within the timeframe established in the schedule. Thus, there arises the need for tools that support and optimise the design of these activities, providing partially prepared design elements so that the time allocated for their execution is not wasted on actions previously performed in earlier stages.

To operationalise these pedagogical principles within a DG context, technological tools are essential — particularly those capable of bridging theoretical understanding with practical application. Thus, HyperCAL^{3D}, software developed within the field of educational technology, provides specific tools for designing teaching activities tailored to the intrinsic characteristics of Descriptive Geometry. In addition to faceted solid modelling, orthographic view generation, and descriptive operations, HyperCAL^{3D} includes an environment for creating and arranging printable layout sheets.

The flexibility and modularity of this environment allow for the proposal of multiple activities framed within unified thematic contexts, capable of fostering learning experiences grounded in complex concepts and predominantly supported by hands-on practice.

Since its development, HyperCAL^{3D} has been systematically employed in a wide range of educational activities targeting Architecture and Engineering students at UFRGS. These activities pursued a dual objective: on one hand, to develop and enhance psychomotor skills such as perception, tool handling, and hand-instrumented drawing; on the other, to consolidate key concepts through the resolution of design problems via DG techniques.

The objective of this study is to propose an innovative approach to designing DG learning activities, using the HyperCAL^{3D} platform to align cognitive and psychomotor learning objectives, thereby fostering student engagement and enhancing the learning process through the integration of Design-Based Learning (DBL) and Integrated Thematic Instruction (ITI) principles.

The following sections present the articulation of DBL and ITI principles in the design of DG learning activities, the integration of cognitive and psychomotor objectives, and an analysis of the pedagogical impacts observed through the use of HyperCAL^{3D}.

2. Materials and Methods

The design of thematic activities in DG is structured through the integration of Design-Based Learning (DBL) and Integrated Thematic Instruction (ITI) principles. These pedagogical approaches provide conceptual and procedural requirements that are aligned and translated into design specifications within the HyperCAL^{3D} platform. The software serves as a platform for both designing and implementing tasks, enabling the creation, modification, and testing of models that are used in the instructional activities. Thematic activities are the final outcome of this process, which is iterative and subject to verification from both pedagogical frameworks.

2.1. Design-Based Learning as a Framework for Practical and Cognitive Integration

Design-Based Learning (DBL) is an educational strategy centred on student engagement in authentic design processes to promote the construction of knowledge through practical and meaningful experiences. Grounded in constructivist and constructionist theories (Piaget, 2013; Papert, 2020), as well as experiential learning theory (Kolb, 2014), DBL fosters active learning by integrating problem-solving, creativity, and collaboration.

In this study, DBL provides the pedagogical basis for structuring activities that are both intellectually and physically engaging, particularly in a discipline like DG, which demands the development of spatial reasoning and manual skills. The principles guiding the implementation of DBL in this context include:

- **Challenge-based learning**, involving open-ended and real-world problems that motivate students to seek creative and functional solutions (Fortus et al., 2004);
- **Iteration and prototyping**, wherein the process unfolds through continuous cycles of ideation, implementation, testing, and refinement, encouraging critical thinking (Kolodner et al., 2003);
- **Interdisciplinary integration**, as solutions demand the coordinated application of knowledge from various fields, thereby strengthening competencies (English, 2009);
- **Reflection and metacognition**, where students are prompted to reflect on their design choices, strategies, and learning progress during the iterative stages of a project. For instance, after completing an orthographic projection, students may be encouraged to assess how their visualisation of the object evolved and how this understanding influenced their subsequent design decisions (Mehalik et al., 2008);
- **Collaboration and collective authorship**, since DBL values teamwork, where negotiated decisions promote the social construction of knowledge (Hmelo-Silver et al., 2007);

- **Authenticity and relevance**, as projects should have practical applications, linking school content to real-world situations (Barak & Doppelt, 2000).

Within this framework, DBL fosters an environment where both cognitive and psychomotor objectives are seamlessly integrated. It enables students to apply theoretical knowledge to real-world challenges while simultaneously honing their practical drawing skills, ensuring that learning is both conceptual and hands-on. The application of DBL in DG seeks not only to improve content mastery but also to increase student motivation and engagement by contextualising learning in relevant, purposeful activities.

2.2 Integrated Thematic Instruction for Structured Conceptual Progression

Integrated Thematic Instruction (ITI) is a pedagogical approach that organises teaching around unifying themes, making learning more meaningful by connecting concepts across different domains and aligning them with students' lived experiences. According to Beatty (2009), ITI values the coherence of content, the integration of skills and knowledge, and the use of diverse methods to engage students cognitively, emotionally, and physically.

In the context of Descriptive Geometry (DG), ITI is employed to organise activities around a central design theme that unfolds throughout a sequence of sessions. This unified theme serves as the conceptual backbone of the learning experience, enabling the integration of multiple geometric concepts into a coherent and cumulative learning pathway.

The implementation of ITI in this study is guided by the following principles (Beatty, 2009):

- **Use of a unified theme related to the subject matter**: For example, students might work on a semester-long project centred around the design of a mechanical connector or architectural element. This object serves as the anchor for successive tasks involving projections, sections, auxiliary views, and intersections;
- **Focus on primary learning objectives**: Each phase of the project is linked to specific DG learning goals, such as understanding orthographic representation or mastering spatial transformations, allowing for curricular components to be addressed in a logical sequence;
- **Design of varied and progressively complex activities**: Activities range from the simple construction of basic geometric solids to more advanced problems involving combinations of solids and descriptive operations. Each activity includes cycles of experience, analysis, and abstraction. For instance, students may initially construct a prism, then rotate it to analyse its projections in different orientations, and finally perform a sectional cut to evaluate internal geometry;
- **Provision of instructional resources**: HyperCAL^{3D} is used to provide dynamic, manipulable 3D models and printable project sheets, offering both virtual and physical interaction with the design object. These resources serve as visual and functional supports that aid in concept internalisation and skill development;
- **Evaluation through authentic practices**: Rather than relying solely on standardised tests, evaluation is conducted via design tasks that result in artefacts or digital submissions. For example, students submit layout sheets showing their design object in multiple views and configurations. Peer review, collaborative development, and structured self-assessment are encouraged to enrich the learning process and reinforce accountability.

This thematic integration ensures that knowledge is not fragmented but interconnected, as students revisit the same object through different DG operations. As a result, concepts are not taught in isolation but situated within the broader context of the object's evolving geometry.

Furthermore, the repetitive use of a single object across multiple tasks enhances students' familiarity with the modelling tool and deepens their understanding of spatial relationships, reducing the cognitive load associated with learning new geometry at every stage. HyperCAL^{3D} supports this continuity by allowing the same model to be reused, edited, and reinterpreted throughout the instructional sequence.

In summary, ITI in this context serves to strengthen the coherence and retention of DG concepts by organising content around a meaningful theme, providing structured progression, and offering opportunities for reflection and practical application. When combined with DBL, this approach fosters deep, transferable learning that is both technically rigorous and pedagogically sound.

2.3 HyperCAL^{3D} as a Pedagogical and Technical Mediation Tool

HyperCAL^{3D} is a software tool specifically developed to support the teaching and learning of DG, providing an environment that bridges theoretical knowledge and hands-on application. By offering functionalities tailored to the demands of geometric representation—such as faceted solid modelling, orthographic projection, section, extrusion, and the generation of auxiliary views—HyperCAL^{3D} serves as both a drawing instrument and a didactic platform.

Since its development in 2006, HyperCAL^{3D} has continually evolved, adding features that support a wide range of DG operations. The tool enables students to create three-dimensional models, manipulate spatial structures, and visualise the real-time effects of descriptive methods. More recently, it has also integrated a layout module for the generation of printable project sheets, reinforcing the link between digital modelling and manual technical drawing.

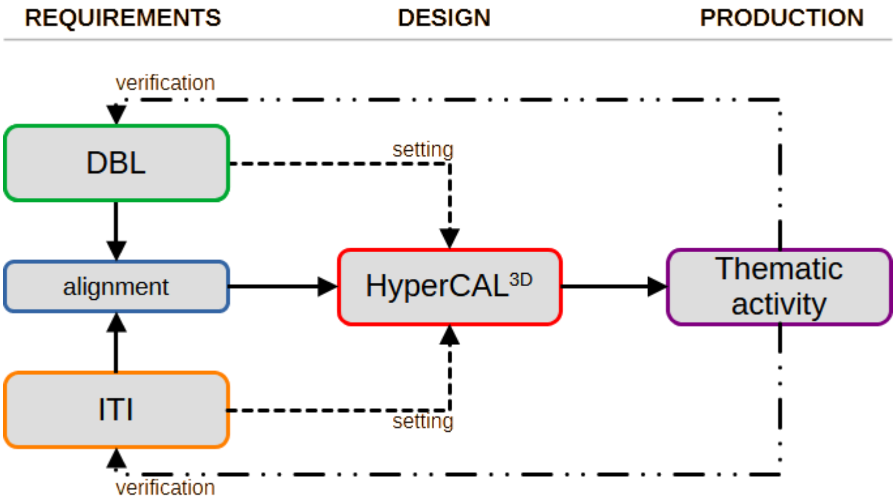

Fig. 1. Schematic representation of the methodological framework.

In this study, HyperCAL^{3D} plays a central role in the materialisation of activities designed within the frameworks of Design-Based Learning (DBL) and Integrated Thematic Instruction (ITI). The requirements derived from these approaches—such as challenge-based design tasks, cross-disciplinary integration, and iterative development—are translated into concrete learning experiences using the platform's modular environment.

Each thematic project begins with the selection or construction of a base object within HyperCAL^{3D}. This object is designed to be adaptable, enabling the introduction of multiple descriptive operations across a series of instructional steps. For example, students might begin by constructing a simple geometric volume such as a hexagonal prism, then gradually apply transformations, sections, and auxiliary views to solve spatial problems associated with mechanical or architectural applications.

The use of a consistent digital model throughout the sequence allows for the progressive layering of geometric knowledge, minimising cognitive overload and facilitating deeper conceptual connections. In addition, the software's interactivity enhances spatial perception by allowing students to rotate, slice, and examine the structures of solids from multiple perspectives—something that is difficult to achieve with static representations.

Furthermore, HyperCAL^{3D} plays a crucial role in enhancing psychomotor skills by allowing students to manipulate virtual tools with precision. These tools replicate the functions of traditional technical drawing instruments, enabling students to practise the fine motor control necessary for accurate, hand-drawn representations before moving on to the manual execution of their designs. Students can export these virtual constructions into layout sheets and reproduce them using conventional drafting methods, reinforcing the connection between hand-instrumented skills and spatial reasoning.

By integrating cognitive objectives (e.g., understanding projection systems) with psychomotor objectives (e.g., performing precise constructions), HyperCAL^{3D} allows for the design of meaningful, practice-oriented tasks aligned with professional standards. It becomes not only a content delivery tool, but a dynamic workspace where students engage with DG concepts through design problems that reflect real-world complexity.

In sum, HyperCAL^{3D} provides the technological infrastructure that enables the application of DBL and ITI in DG education. It operationalises the pedagogical goals of this study, offering both flexibility and structure for the design, implementation, and evaluation of learning experiences that are intellectually rigorous and practically grounded.

2.4 Operational Alignment of DBL and ITI within the HyperCAL^{3D} Environment

The methodological articulation between Design-Based Learning (DBL), Integrated Thematic Instruction (ITI), and the HyperCAL^{3D} platform is illustrated in Fig. 1. The two pedagogical approaches provide the conceptual foundations and didactic requirements, which are then aligned and operationalised within the design environment offered by HyperCAL^{3D}. This alignment enables the creation of three-dimensional models and tasks that meet both cognitive and psychomotor learning objectives. The software acts as a central hub where content is configured according to the unified theme and iteratively refined based on feedback from both DBL and ITI. The final outcome of this process is a set of thematic activities that integrate DG content with real-world design challenges, offering students meaningful and multidimensional learning experiences.

Together, the integration of DBL, ITI, and HyperCAL^{3D} creates a cohesive and dynamic learning environment where students can engage with complex geometrical concepts both cognitively and practically. This synergy not only enhances students' understanding of Descriptive Geometry but also prepares them for real-world design challenges.

3. Results and Discussion

The principles of DBL and ITI are materialised through a sequence of activities developed within the HyperCAL^{3D} environment. Each project begins with a geometric problem grounded in a unified theme—such as designing a mechanical part or architectural feature—that evolves through progressive stages. In an initial task, for example, students may be asked to construct a 3D model of a prismatic component with specific dimensional and positional constraints. Subsequent tasks involve descriptive operations such as generating auxiliary views, performing sections, or verifying spatial relationships through intersections.

As students navigate these activities, they engage in iterative refinement—modifying their models based on feedback or new requirements—thus experiencing design as a dynamic and responsive process. Moreover, because these problems are situated in contexts related to students' future professional practice, they encourage the application of theoretical knowledge to practical scenarios.

The use of HyperCAL^{3D} enables students to operate within a virtual environment that mimics professional design conditions while scaffolding the acquisition of spatial and instrumental competencies. This approach not only supports the cognitive development required to master DG concepts but also promotes psychomotor skill acquisition through active manipulation of design elements.

In sum, DBL within this study is not limited to hands-on activity; it represents a structured, reflective, and context-driven learning experience that integrates cognitive, psychomotor, and social dimensions of learning. When aligned with Integrated Thematic Instruction (see Section 2.2), DBL contributes to a cohesive and multidimensional pedagogical strategy.

3.1. Structuring Thematic Design Activities in HyperCAL^{3D}

Each object is designed to enable different types of activities. As new content is introduced and new learning objectives are defined, students return to the same object, enhancing it through iterative cycles.

To be selected as the theme of a learning cycle, the design of the object must reflect the articulation between the principles of Design-Based Learning (DBL) and the components of Integrated Thematic Instruction (ITI). In this process, the unified theme and provision of resources are guided by principles of authenticity and relevance, including opportunities for interdisciplinary integration whenever possible.

Following the definition of the theme and the modeling of the first prototype, it is assessed whether the object enables the development of a range of activities that evolve progressively in complexity through iterative cycles. At this stage, it is also evaluated whether such opportunities present an authentic challenge for students to engage both cognitive and psychomotor skills.

If the object meets the proposed criteria, the activity cycles are developed and refined with a focus on the primary learning objectives of each stage of the course. At this point, principles of collaboration and collective authorship are taken into account. Each cycle is designed to provide moments of group collaboration and discussion, as well as opportunities for individual production and reflection.

Finally, each cycle is linked to an assessment system aligned with the proposed objectives, incorporating both formative and summative approaches. This stage includes assessment by the teacher, peer review, and self-assessment. Evaluation is understood as a parallel process that occurs throughout the cycle, supporting action through reflection.

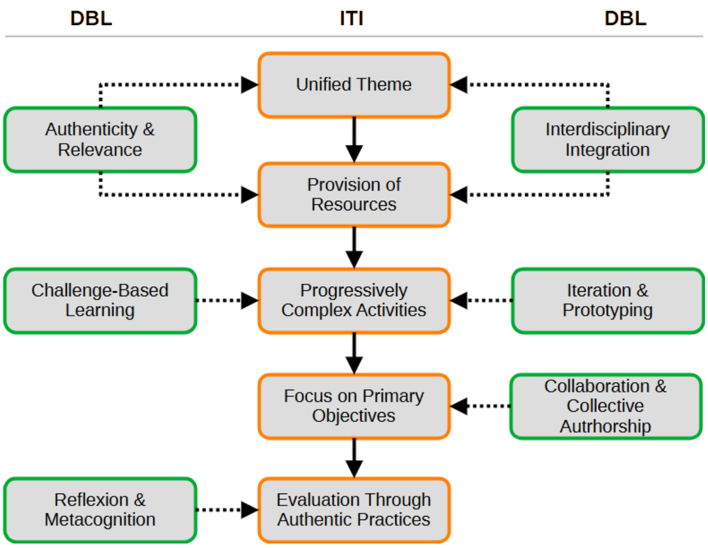

Fig. 2. Articulation between DBL principles and ITI components.

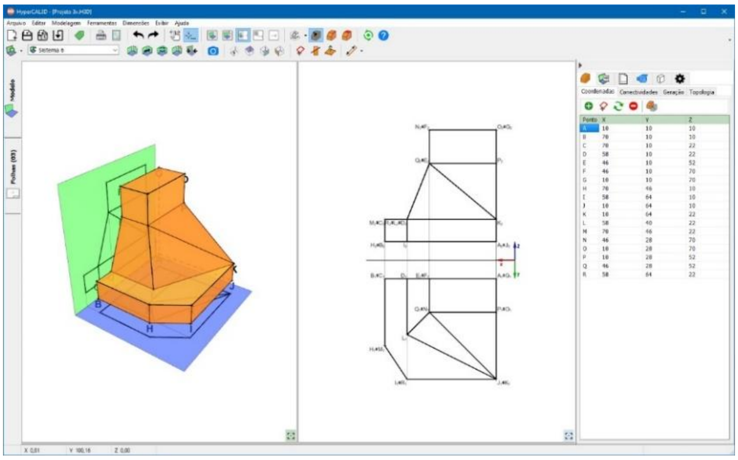

Fig. 3. HyperCAL^{3D} window.

The diagram shown on Fig. 2 illustrates how DBL principles (in green) align with ITI components (in orange) to guide the design of object-based learning cycles. The structure emphasizes the definition of a unified theme and the provision of authentic resources, which support progressively complex activities focused on primary objectives, along with collaboration, iteration, and authentic assessment practices.

3.2. Integration of Cognitive and Psychomotor Objectives

The progression of cognitive and psychomotor objectives occurs simultaneously. In each cycle, the increasing complexity of the objectives drives both knowledge construction and the development of new skills.

Based on the analysis of the three-dimensional object in HyperCAL^{3D} (Fig. 3), students create orthographic projections using paper and drawing instruments. From a cognitive perspective, this stage enables the understanding of projection systems, coordinate systems, and the representation of three-dimensional objects in two dimensions. From a psychomotor perspective, it activates processes of perception, preparation, and guided response.

The orthographic views facilitate the study of the specific spatial positions of each element (faces, edges, and vertices) and their relative locations. In this primarily theoretical stage, hands-on experimentation enhances comprehension and reinforces the underlying concepts — often using empirical and concrete objects.

The analysis of the specific positions of each object element encourages reflection on potential design challenges, such as determining true sizes and edge views (Fig. 4), so that the object can be modified and expanded. As a result, designing new elements generates the need for auxiliary views — at this stage, students reanalyse the three-dimensional object and return to paper to execute the necessary projections to meet new design requirements (e.g., designing a window on a wall with a foreshortened projection, or modifying the slope of an oblique roof).

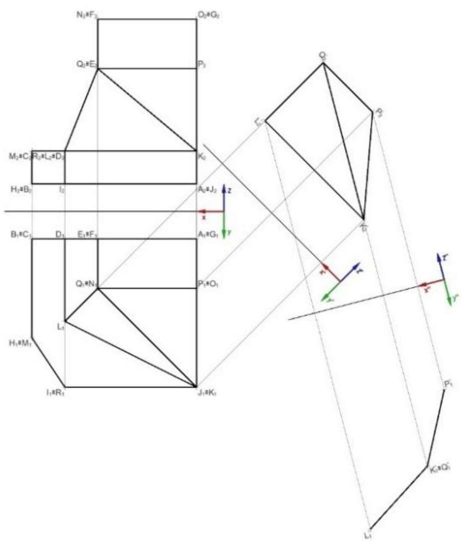

Fig. 4. Sucessive auxiliary views to find the angle between two faces.

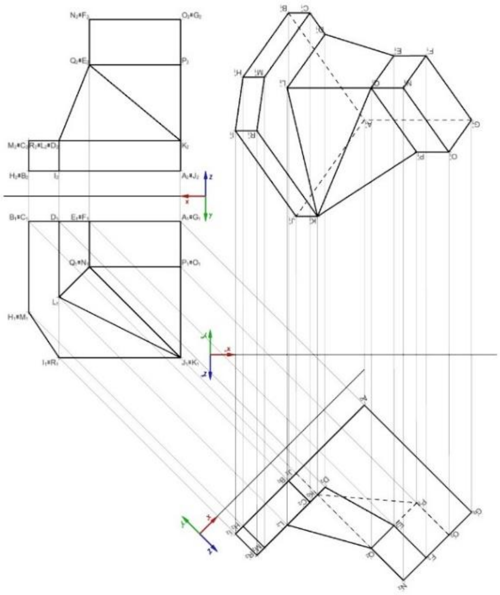

Fig. 5. Sucessive auxiliary views to find an axonometric perspective.

At the end of the modification process, students validate the outcomes by constructing axonometric perspectives (Fig. 5), using successive auxiliary views as a tool. Whenever possible, the construction of physical prototypes is required, adding further complexity to the objectives (Fig. 6).

3.3. Student Engagement and Learning Outcomes

The approach used is characterised by three key features: the extensive practice of hand drawing as a design tool, the continued use of a single object throughout the cycle, and the constant support provided by HyperCAL^{3D} during the process.

Drawing practice not only supports the development and refinement of essential skills for future designers, but also enhances the understanding of new concepts. Hands-on work helps establish meaning in relation to the topic being addressed.

Similarly, the use of a unified theme offers students greater confidence, as new content is applied to a familiar object, reducing the cognitive load required to integrate new knowledge into their cognitive structure. HyperCAL^{3D} plays a fundamental role by allowing the proposed objects to be analysed from multiple perspectives and offering tools for students to virtually practice the processes that they will later carry out on paper.

The selection of a relevant theme and the continued use of a single object throughout the learning cycle reinforce the idea of student ownership. The modifications made to the object throughout the course result in unique solutions, and by the end, each student has their own version — the outcome of their decisions and actions. The engagement achieved stems from the affective connection that students build with their creation.

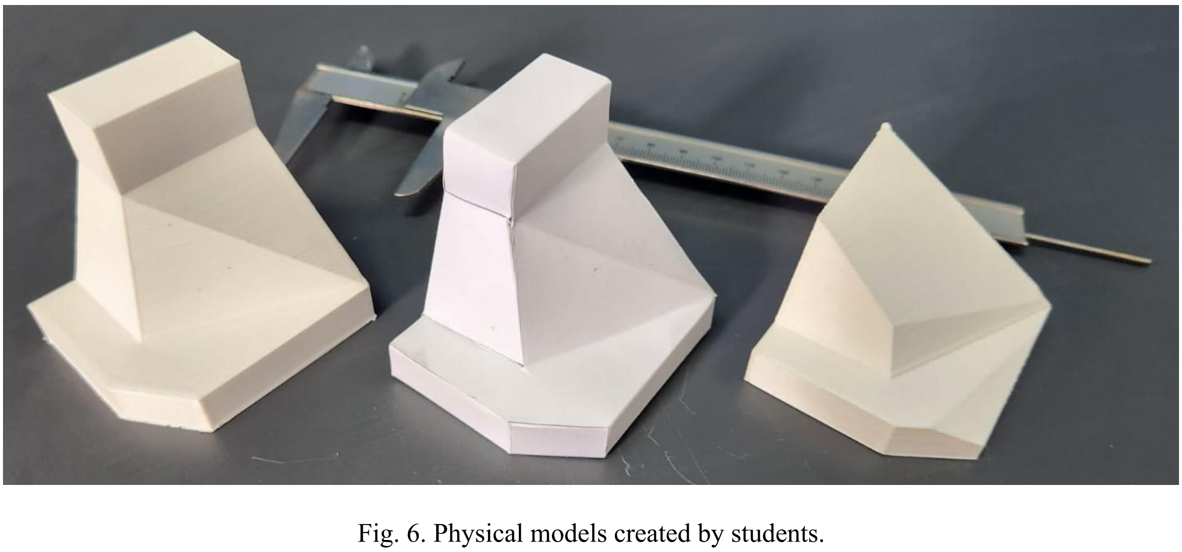

Fig. 6. Physical models created by students.

3.4. Pedagogical Impacts and Instructional Reflections

The articulation between Design-Based Learning (DBL) and Integrated Thematic Instruction (ITI) is achieved through the construction of learning activities based on tangible elements closely related to students' lived realities. This approach often results in the creation of complex objects, which can pose challenges to their reuse throughout the instructional cycle. However, the use of HyperCAL^{3D} enables these objects to be maintained across multiple learning phases, allowing certain steps to be carried out virtually.

This capacity significantly enhances the efficiency of iterative cycles. Time that would otherwise be spent redrawing the objects or preparing new starting points can instead be allocated to exploring more advanced concepts or engaging in enriched hands-on activities. In this sense, technology not only supports logistics but also contributes to the deepening of learning.

Moreover, this pedagogical approach reinforces the principles of continuity and progression. By enabling students to return to the same object across different stages, their cognitive and psychomotor development is scaffolded in a more cohesive manner. Learners gain a greater sense of ownership over the process, as they perceive the evolution of their work as a narrative they construct and refine.

From an instructional standpoint, this model demands that educators adopt a dynamic role. They must anticipate potential learning paths, provide meaningful feedback throughout each iteration, and continuously adjust the environment to sustain student engagement and autonomy. Reflection is not limited to student performance, but extends to teaching practice itself—encouraging educators to evaluate the impact of their strategies and to refine the integration between conceptual understanding and technical skill development.

3.5. Contributions and Limitations of the Proposed Approach

The integrated approach combining DBL and ITI, supported by the HyperCAL^{3D} platform, offers significant contributions to the teaching and learning of DG and design-based skills. Among its key benefits is the possibility of promoting deeper student engagement through iterative learning cycles, personal ownership of the learning object, and the progressive development of cognitive and psychomotor skills. The consistent use of a single object throughout the instructional cycle, coupled with extensive hands-on drawing practice and the virtual affordances of HyperCAL^{3D}, fosters a more meaningful and contextually anchored learning experience.

Furthermore, this approach encourages collaboration, critical thinking, and reflective practices by integrating theoretical concepts with applied design tasks. It supports interdisciplinary connections and allows students to progressively refine their skills through increasingly complex tasks that mirror real-world challenges.

However, some limitations must be acknowledged. The approach requires a significant initial investment in terms of planning, resource development, and teacher training, particularly to ensure the effective use of HyperCAL^{3D} and the alignment of instructional goals across cycles (Fig. 7). Additionally, the complexity of the objects used—while beneficial for depth of learning—can pose difficulties for less experienced students or those with limited spatial reasoning abilities, potentially increasing the cognitive load.

Another challenge lies in the scalability and adaptability of the model to different educational contexts. While the approach has shown positive results in the specific implementation described here, further studies are needed to assess its generalisability across institutions with different infrastructures, curricula, and student profiles.

Despite these limitations, the proposed approach represents a valuable contribution to pedagogical practices in technical and vocational education, offering a flexible yet structured model that aligns learning processes with authentic design experiences.

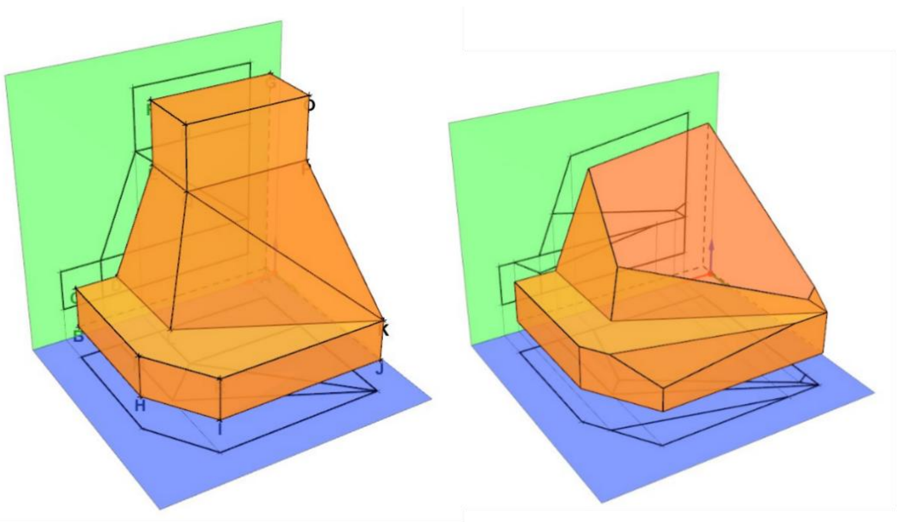

Fig. 7. Models created in HyperCAL^{3D}, after the editing process in paper.

3.6. Summary and Final Remarks

The articulation between DBL and ITI, supported by HyperCAL^{3D}, offers a pedagogical model that is both conceptually robust and practically grounded. The use of tangible objects as anchors for iterative learning cycles enables students to progressively develop their cognitive and psychomotor skills, while also fostering personal engagement through ownership and authorship. By reducing preparation time through virtual simulations and integrating theoretical concepts with hands-on practice, the approach enhances both instructional efficiency and student motivation.

4. Conclusions

This study presents a pedagogical model that integrates Design-Based Learning (DBL) with Integrated Thematic Instruction (ITI), supported by the HyperCAL^{3D} platform, to enhance the teaching and learning of Descriptive Geometry (DG). This approach uses tangible, theme-based objects that evolve through iterative learning cycles to allow the simultaneous development of cognitive understanding and psychomotor skills.

Applying this model showed that engaging with a single object that becomes more complex over time fosters student ownership, supports conceptual learning and encourages reflection through design-oriented problem solving. Articulating DBL principles with ITI components proved effective in structuring meaningful, contextually relevant activities aligned with authentic professional practices.

HyperCAL^{3D} played a central role in this process by not only simulating design conditions, but also enabling continuity and progression in the learning experience. The platform reduced logistical constraints and enhanced instructional efficiency, allowing for deeper exploration of the theoretical and applied aspects of DG.

Despite the promising results, the approach also revealed certain challenges, particularly with regard to the demands of the initial planning stage and the cognitive load imposed by complex design tasks. These limitations highlight the importance of careful implementation strategies and further research into the model's adaptability to different educational settings.

In conclusion, integrating DBL, ITI and digital tools such as HyperCAL^{3D} provides a conceptually robust and practically grounded pedagogical framework. It promotes active, reflective and interdisciplinary learning and has the potential to significantly enrich technical and vocational education by aligning instructional strategies with contemporary design practice.

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Social perception of public buildings: Urban users perspective

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Abstract. Humans have been creating spaces in line with their needs since the first moment of their existence. These spaces align with various parameters such as function, purpose, culture, technology, economy, and climate. Public buildings, one of these spaces, are built by the state to meet society's needs. Public buildings, built for various purposes and functions such as health, education, administration, military, and management, constitute an important part of the city by reflecting the characteristics of the period and society in which they were built like other buildings. Humans, another part of the city, perceive and make sense of their environment through various visual, auditory, physical, and semantic tools. Architectural features of buildings, such as style, function, location, color, form, and material, play an important role in human perception of their environment. Today, public buildings in our country are generally designed with similar architectural styles, colors, forms, and materials, regardless of function. In different regions, public buildings with almost the same characteristics are encountered, where factors such as changing climate, topography, culture, context, etc., are not considered in their design. In this context, the study aims to determine how the users perceive this physical similarity of public buildings and what kind of results this perception leads to. Within the scope of this purpose, a survey study was conducted to evaluate the visual environmental perception of public buildings in the Patnos district of Ağrı. In line with the data obtained as a result of the study, it was determined how public buildings with similar architectural styles were interpreted by the users.

Keywords: Public Buildings; Perception; Style; Function; Urban User

1.Introduction

A person in a space defines and makes sense of his/her surroundings through the relationship he/she establishes with his/her environment. In this non-stationary relationship, the individual's acquisition of information from the environment is defined as perception. In contrast, interpreting the information acquired with our sense organs in the mind is defined as perception (Atkin et al., 2012).

Humans and the environment are in a continuous and active relationship. People try to perceive their environment according to many parameters, such as experiences, sociocultural structure, economic status, age, and gender (Aydınlı, 1992). Rapoport (1982) defined the perception of the environment as the process of making choices and evaluations by describing the environment in line with the reflections of the information obtained through the sense organs in the mind. The realization and interpretation of the environment through the spaces that make up the environment constitute the common working area of architecture and perception.

Human beings, who have needed space from the first moment of their existence, have built structures with various functions to meet this need. While each building defines the interior space, it also defines the exterior space. Bruno Zevi (1990) states that "Every building helps to create two spaces. The 'interior space' determined by the building itself and the 'exterior space' (urban space) between this building and neighboring buildings." (Zülkadiroğlu, 2013).

Buildings, which play an active role in shaping the urban space, are constructed in line with the cultural, social, economic, environmental, physical, geographical, physical, and cultural characteristics of the period, society, and time in which they are built. Buildings constructed in line with these characteristics help form a city's identity as one of the urban identity elements. These buildings, which establish a relationship with the city and people, form urban memory and develop a sense of belonging over time. Urban memory and spatial perception, which occur in line with the society's relationship with the city and buildings, make it possible to recognize the past in the present by establishing a link between the past and the future (Cengiz Taşlı et al., 2023).

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Buildings that are built uniformly without considering factors such as location, society, culture, and geography cause damage to the urban identity. In addition, the formation of ordinary environments with uniform construction reduces diversity and negatively affects people's perception of their environment (Alexander et al., 1977). For the environment to be perceived correctly, harmony and diversity must be balanced. The environment becomes ordinary or complex when this balance is not achieved (Kaplan & Kaplan, 1989). This situation negatively affects people's sense of belonging.

The city is in an active relationship with its users. The design and planning of the structures, equipment, and vehicles that make up the urban environment affect spatial perception (Lynch, 1979). In this context, qualities such as architectural formation, color, size, and texture of the buildings that make up the environment play an important role in forming spatial perception. Not only the formal characteristics of the buildings, but also factors such as their relationship with other buildings, their relationship with the city, and the balance of harmony and diversity also affect the perceptibility of the environment (Kızılkan & Yeşildal, 2021). Building groups, which form an important part of the urban environment and have an important place in urban life, strongly influence the perception of the environment. The quality of the physical environment increases when the formal characteristics of these building groups are well-designed with their surroundings. This situation allows the space to be diversified in harmony, the space to be perceived, and the character of the space to be formed (Cengiz Taşlı et al., 2023).

Buildings, which form the boundaries of the urban environment, enable perception to reach the user with their formal qualities and the spaces they define. Buildings enable users to get information from their surroundings with qualities such as color, texture, form, relationship with the surrounding buildings, and the spaces they form the boundaries of. In this context, buildings should be designed by considering the formal qualities of their facades and the relationship they establish with their surroundings (Karakoç, 2004).

Building groups play an active role in forming the urban fabric and influencing user perceptions of the environment, with features such as their location within the city, functional setup, and architectural design (Tanrıbir & Akten, 2020). The diversity of building groups, which has an important place in forming urban spaces, affects the perceptibility of the space. Public buildings have the most functional diversity among the building groups that interact directly or indirectly with users.

Public buildings are built by the state to carry out state affairs. These buildings vary according to their function, such as education, health, or administration. The design of public buildings is based on the "Public Building Standards Guide" prepared by the Ministry of Environment, Urbanization, and Climate Change. The guide includes criteria such as land selection, expropriation, space dimensions, and principles of use (URL-1).

Public buildings, which are expected to be constructed in line with specific criteria, do not have a set criterion for facade design. Despite this, the architectural style of the past periods is imitated by using building elements such as iwan, arches, borders, and crown gates, which are prominent in Seljuk and Ottoman architecture in public buildings built in today's cities. Most of our cities have public buildings designed with similar architectural styles, ignoring the urban texture, geographical features, physical requirements, etc. (Fig. 1). This situation affects the perceptibility of the buildings and causes identity confusion in cities (Özkaynak, 2021).

The use of historical forms in architecture without adapting them to the requirements of the period, society, location, and space prevents the formation of a bond between the building and the user (Kazmaoğlu & Tanyeli, 1986). Trying to create new spaces by imitating the old is characterized as disrespect to the spirit of the space (Norberg-Schulz, 2001). In addition, with the imitation approach, the heritage left to future generations will not be able to establish a strong connection between the past and the future and will create an architectural formation without identity (Pasin & Varinlioğlu, 2018). This anonymous situation makes it difficult for the building to interact with the user. The space that cannot interact with people cannot be perceived correctly.


a b c

Fig. 1. a.Çamardı Government House (URL-2), b.Çayeli Government House (URL-3), c.Yıldırım Beyazıt University (URL-4)

This study examines the representation of public buildings designed in a similar architectural style in the urban context and their effects on user perception. Accordingly, public buildings with different functional qualities in the designated study area were analyzed in the context of user experiences and spatial memory. The data obtained provides a comprehensive assessment of the current morphological and typological situation; at the same time, it allows for the reading of the architectural identity shaped through user-space interaction. In this context, it is foreseen that these analyses will provide a critical basis for the design decisions of future public buildings and contribute to forming a qualified built environment

2. Working Area

Patnos district of Ağrı was determined as the study area. The distance from the district to the city center is 82 kilometers. The district's population is 123,526 people and is the second largest district of Ağrı in population density (URL-5). The focal point of the district settlement is the city center. While residential and commercial areas are predominantly located in the city center, there are also functions such as health and recreation. While the north of the road (Atatürk Boulevard) that provides transportation between Ağrı and Van provinces is a military zone, public buildings are located in the south.

Patnos district of Ağrı province, which was determined as the study area, is located approximately 82 km from the city center and is the second most populous settlement in Ağrı with a population of 123,526 (URL-5). The spatial organization of the district settlement is primarily concentrated in the city center, which includes residential and commercial areas and buildings for health, recreation, and similar public functions. Atatürk Boulevard, one of the main axes determining the direction of urban development, is surrounded by military areas in the north and public institutions in the south and, accordingly, plays a decisive role in the city's functional distribution and spatial hierarchy. In light of these physical and socio-spatial data, the morphological structure of Patnos city center constitutes a sample worth examining in terms of the positioning and functional diversity of public spaces.

Public buildings with different functional identities (administrative, security, education, etc.) are located on a common urban axis instead of being scattered in different parts of the district, which has been decisive in selecting the Patnos district of Ağrı as the study area. The fact that these buildings were built with similar architectural styles and forms of expression is remarkable regarding spatial continuity and formal integrity. This situation provides a critical basis for understanding the physical layout and the representational value of public buildings in constructing the city's perceptibility, legibility, and urban identity. Therefore, Patnos district constitutes a qualified sample area in terms of questioning the role of public architecture in the urban context and examining the effects of architectural shaping on urban identity (Fig. 2).

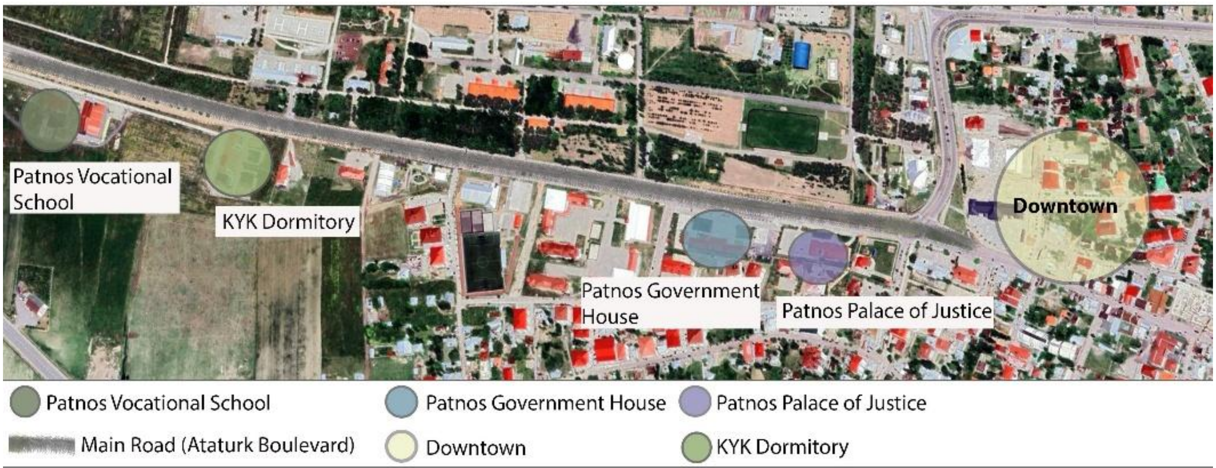

Fig. 2. Location of the Study Buildings in the City

Within the scope of this study, the perceptibility of public buildings designed in a similar architectural style despite having different functional qualities is examined at the urban scale. In this respect, the main criterion is that the buildings to be selected should have a common design language despite the diversity of their functions. In this context, Patnos Palace of Justice, Patnos Government House, Patnos Vocational High School, and KYK Dormitory, which are located on Atatürk Boulevard and represent different public functions such as the judiciary, administration, education, and accommodation, but have similar morphological and aesthetic characteristics, were selected as the study sample. These buildings provide a basis for a comparative analysis of formal integrity and perceptual continuity within the built environment, both in terms of their architectural expression and positioning within the city (Fig. 3).

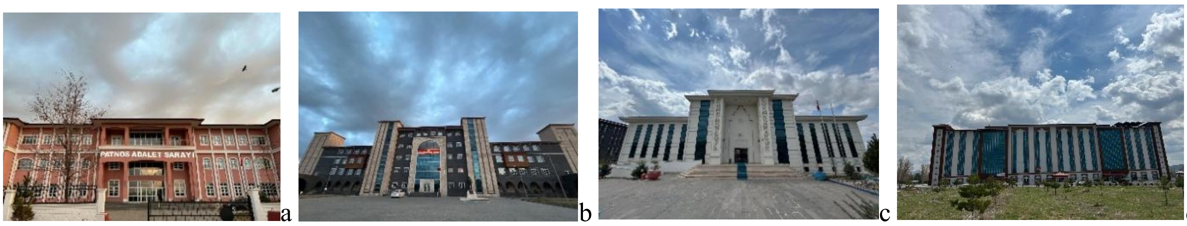

Fig. 3. a.Patnos Palace of Justice, b.Government House, c.Vocational School, d.KYK Dormitory

Patnos Palace of Justice is the closest of the selected buildings to the city center. The building, which has three floors and a rectangular form, is pink in color, and white is preferred around the windows. It was designed to be more prominent to accentuate the building's entrance, and an arched entryway was introduced to enhance its visual significance. The right and left end parts of the building are wider than the overall building, and it was designed in 2013 as a symmetrical building with general lines.

Patnos Government House started to be used in 2017. Different colors and materials were preferred to emphasize the entrance. It was tried to create a semi-open space with arches on the ground level. The entrance left and right parts of the building differ from the primary color and are designed as symmetrical buildings with higher heights.

The construction of Patnos Vocational School started in 2013. The building, which has two floors and a rectangular form, is white, and the entrance section is emphasized by making it more prominent and higher. The entrance was inspired by the crown gate, one of the prominent features of Seljuk architecture. The building, which is decorated with Seljuk star motifs in places, was built symmetrically.

KYK Dormitory is a single building divided into male and female dormitories. For this reason, the building has two entrances, which are emphasized with glass facades. Like the school building, the building is decorated with Seljuk star motifs in places, and Seljuk architectural patterns are used to frame the glass parts of the building. The right and left sides of the building are higher in height and were built in 2015 as a symmetrical building.

3. Methodology

In line with the study's aim, the visual environment perception of urban users through public buildings was evaluated. The semantic differentiation scales Hershberger and Cass (1988) developed for "measuring the meanings of designed environments" were used to examine users' perceptions of the visual environment.

Hersberger and Cass produced ten different factors, including their primary scale, secondary scale, and alternatives of these scales in the evaluation technique they developed (Minez, 2013). Within the scope of the study, general evaluation, aesthetic evaluation, spatial evaluation, strength, organization factors, and the scales of these factors were utilized based on the factors developed by Hersberger and Cass. The study also incorporated an impact/image factor alongside these variables (Table 1). A questionnaire form consisting of closed-ended questions about the six factors was prepared. In the questionnaire form, the participants were asked to evaluate each structure separately in line with the determined factors. The form concluded with questions addressing all the structures examined in the study. The questions were asked to be answered in a multiple-choice manner in line with the adjectives determined. The researchers assessed the visual impact of the identified building group based on the responses provided.

The study was conducted on public buildings located on Atatürk Boulevard and designed in a similar architectural style despite having different functional identities. Patnos Vocational High School students were identified as the target group in the survey application, which was carried out to evaluate user perception and comparatively analyze the perceptual approaches of individuals who have past experience with the city and individuals who have recently arrived in the city for university education. A total of 129 students participated in the survey conducted online voluntarily.

4. Results

In order to assess the perception of the visual environment of public buildings, a survey was conducted in April 2025. The questionnaire consists of three parts. The questions in the first part consist of questions about personal information such as age, gender, and frequency of use in the study area. In the second part of the questionnaire form, questions were included for the participants to individually analyze the Patnos Palace of Justice, Patnos Government House, Patnos Vocational School, and KYK Dormitory structures determined within the scope of the study in line with predefined evaluation criteria. In the last part of the questionnaire, some questions aim to compare the four buildings as a whole and enable the participants to make comparative evaluations based on parameters such as similarity and distinguishability between the buildings. The analyses highlight the most and least preferred options by the participants in response to the multiple-choice questions.

Table 1. Factors and scales used in the visual environmental assessment of public buildings

Factors	Scales
General Evaluation	Contemporary/traditional, good/bad
Aesthetic Evaluation	Interesting/boring
Spatial Assessment	Clear/uncertain, personal/general
Strength	Small/large
Organisation	Coloured/colourless
Impact/ Image	Reflects/ Does Not Reflect

4.1. Section 1 Results ;

- Of the 129 people who participated in the survey, 79 were female, and 50 were male.
- One hundred twenty-two participants are 18-25 years old, four are 25-30 years old, and three are 30 years old and above. The majority of participants fall within the 18–25 age range.
- 85.3% of the participants (110) have been residing in the district for less than 2 years.
- The road where the public buildings considered in the study are located (Atatürk Boulevard) is used by 52.7% (68 people) of the people every day, 26.4% (34 people) 3-4 days a week, and 20.9% (27 people) 1-2 days a week (Fig. 4).

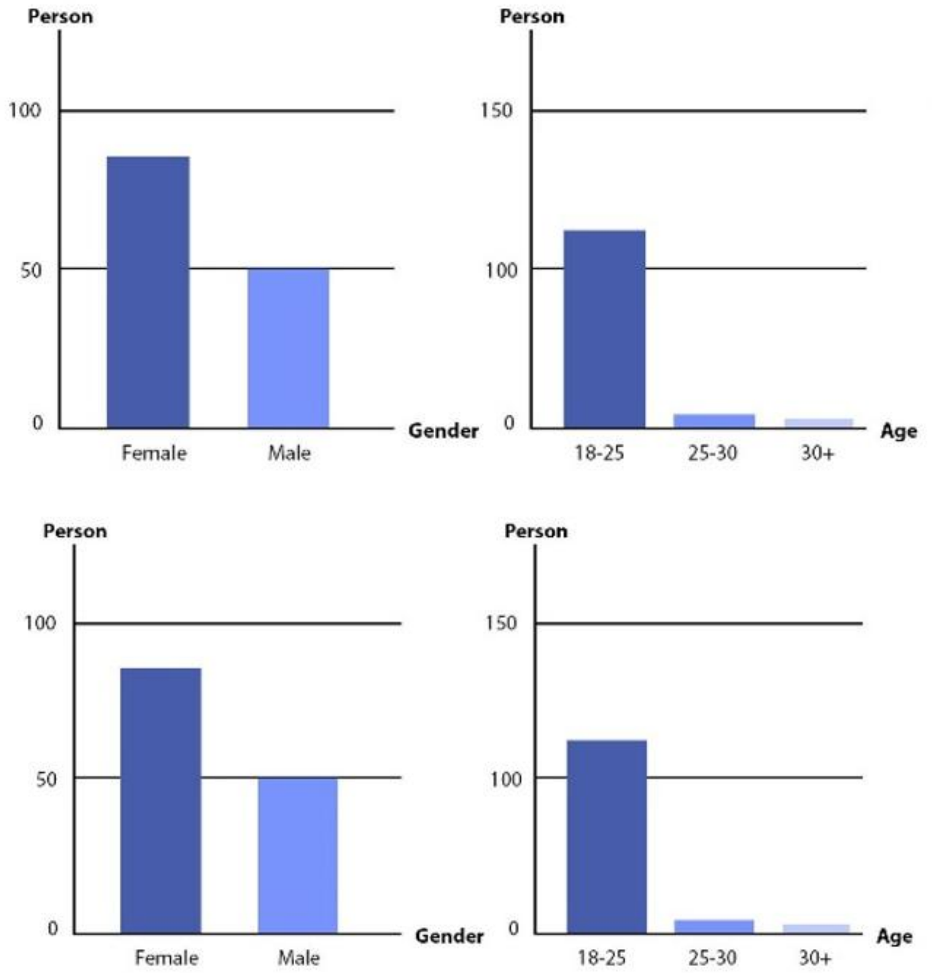

Fig 4. Participants personal information

4.2. Section 2 Results

In the second part of the questionnaire form, questions regarding evaluating the visual environmental perception of Patnos Palace of Justice, Patnos Government House, Patnos Vocational School, and KYK Dormitory were directed to the participants within the framework of six predefined factors. Each building was evaluated separately in line with the relevant factors, and participant responses were collected through multiple-choice questions. Factor-based averages were calculated for each building based on the data obtained; a comparative analysis was carried out between the buildings, and a general evaluation of the relevant section was made.

Evaluation results of the visual environmental perception of Patnos Palace of Justice on users (Table 2);

- 35.6% of the participants evaluated the architectural style of the building as traditional.
- The architectural style of the building was interpreted as good by 46.5% of the participants.
- The facade characteristic of the building was described as ordinary by 53.4% of the users.
- 34.1% of the participants defined the form of the building as clear.
- The dimensions of the building were described as medium by 58.1% of the participants.
- The color of the building was considered medium by 48.8% of the participants.
- 44.1% of the participants stated that the building was considered a public building with its facade design.
- The building does not excite 47.2% of the participants at all.

The results of the evaluation of the visual environmental perception of Patnos Government Mansion by the users (Table 3);

- The architectural style of the building was described as contemporary by 28.6% of the participants.
- The architectural style of the building was interpreted as good by 47.2% of the participants.
- The facade characteristic of the building is ordinary for 34,1% of the users.
- 34,8% of the participants defined the form of the building as clear.
- The dimensions of the building were described as medium by 44.9% of the participants.
- The color of the building was described as medium by 48% of the participants.
- 48.8% of the participants stated that the building was considered a public building with its facade design.
- The building does not excite 36.4% of the participants at all.

Table 2. Results of Evaluation of Visual Environmental Perception of Patnos Palace of Justice

Patnos Palace of Justice	Most preferred answer	Least preferred answer
Do you find the architectural style of the building traditional or modern?	Traditional 46 people	Modern 5 people
What do you think of the architectural style of the building?	Good 60 people	Great 7 people
What do you think about the facade characteristics of the building?	Ordinary 69 people	Very ordinary 18 people
How do you find the form of the structure?	Apparent 44 people	Supereminent 7 people
How do you find the dimensions of the building?	Middle 75 people	Tiny 11 people
What do you think about the colors of the building?	Middle 63 people	Multicoloured 8 people
When you first see the building, is it evident that it is a public building?	Comprehensible 57 people	Painfully obvious 12 people
Does the building excite you?	Unsensational 61 people	Breathtaking 1 people

Table 3. Results of Evaluation of Visual Environmental Perception of Patnos Government House

Patnos Government House	Most preferred answer	Least preferred answer
Do you find the architectural style of the building traditional or modern?	Modern 37 people	Hesitant 11 people
What do you think of the architectural style of the building?	Good 61 people	Awful 6 people
What do you think about the facade characteristics of the building?	Ordinary 44 people	Very ordinary 10 people
How do you find the form of the structure?	Apparent 45 people	Unclear 8 people
How do you find the dimensions of the building?	Middle 58 people	Tiny 6 people
What do you think about the colors of the building?	Middle 62 people	Multicoloured 5 people
When you first see the building, is it evident that it is a public building?	Comprehensible 63 people	Painfully obvious 9 people
Does the building excite you?	Unsensational 47 people	Hesitant 6 people

The results of the evaluation of the visual environmental perception of Patnos Vocational School by the users (Table 4);

- The architectural style of the building was described as contemporary by 28.6% of the participants.
- The architectural style of the building was interpreted as good by 47.2% of the participants.
- The architectural style of the building is ordinary for 34,1% of the users.
- 34,8% of the participants defined the form of the building as clear.
- The dimensions of the building were described as medium by 44.9% of the participants.
- The color of the building was preferred by 48% of the participants as medium.
- 48.8% of the participants stated that it was understood that the building was a public building with its facade design.
- The building does not excite 36.4% of the participants at all.

Table 4. Results of Evaluation of Visual Environmental Perception of Patnos Vocational School

Patnos Vocational School	Most preferred answer	Least preferred answer
Do you find the architectural style of the building traditional or modern?	Traditional 38 people	Hesitant 11 people
What do you think of the architectural style of the building?	Good 60 people	Awful 9 people
What do you think about the facade characteristics of the building?	Ordinary 38 people	Very ordinary 9 people
How do you find the form of the structure?	Apparent 56 people	Supereminent 13 people
How do you find the dimensions of the building?	Middle 67 people	Immense 7 people
What do you think about the colors of the building?	Middle 67 people	Multicoloured 6 people
When you first see the building, is it evident that it is a public building?	Comprehensible 60 people	Incomprehensible 11 people
Does the building excite you?	Unsensational 48 people	Breathtaking 6 people

Assessment results of the visual environmental perception of KYK Dormitory by the users (Table 5);

- The architectural style of the building was defined as traditional by 27.3% of the participants.
- 37.2% of the participants evaluated the architectural style of the building as good.
- 43,4% of the participants found the façade characteristic of the building ordinary.
- The form of the building was clearly understood by 35,4% of the participants.
- 37.2% of the participants defined the dimensions of the building as medium.
- The color intensity of the building was evaluated as medium by 48.8% of the participants.
- When first seen, 41% of the participants thought the building was recognized as a public building.
- The building does not excite 48% of the participants.

Table 5. Results of the Evaluation of the Visual Environmental Perception of KYK Dormitory

KYK Dormitory	Most preferred answer	Least preferred answer
Do you find the architectural style of the building traditional or modern?	Traditional 35 people	Modern 19 people
What do you think of the architectural style of the building?	Good 48 people	Awful 14 people
What do you think about the facade characteristics of the building?	Ordinary 56 people	Very ordinary 6 people
How do you find the form of the structure?	Apparent 47 people	Supereminent 8 people
How do you find the dimensions of the building?	Middle 48 people	Tiny 11 people
What do you think about the colors of the building?	Middle 63 people	Multicoloured 8 people
When you first see the building, is it evident that it is a public building?	Comprehensible 53 people	clearly understandable 15 people
Does the building excite you?	Unsensational 48 people	Breathtaking 6 people

4.3**.** Section 3 Results

In the third part of the questionnaire form, common questions were prepared to make a general evaluation of Patnos Palace of Justice, Patnos Government House, Patnos Vocational School, and KYK Dormitory. The questions asked were to be answered by thinking in common for the four buildings. The section was evaluated based on the answers given. Common evaluation of the buildings (Table 6);

- 37.2% of the participants think there is a similarity between the architectural styles of the buildings.
- 34.8% of the participants think that the similarity between the architectural styles of the buildings positively affects the ability to distinguish the function of the building.

Table 6. Conclusions on General Evaluation

General Evaluation	Most preferred answer	Least preferred answer
Do you think there are similarities between the architectural styles of the buildings?	Resemble 48 people	very similar 10 people
How do you think the similarities between the architectural styles of the buildings affect the distinguishability of the function of the building?	Positive 45 people	Awful 4 people

5. Conclusion

Human beings interact with every created space and perceive and interpret their environment through this interaction. In the process of interpretation, the qualities of the components that make up the environment are very effective. In this context, features such as color, style, material, form, shape, and size of the buildings that define urban spaces help users perceive their surroundings.

Within the scope of this study, the effect of designing public buildings with different functions in Patnos district with similar architectural styles on user perception is examined. The findings obtained through questionnaires revealed that public buildings are generally evaluated as “traditional,” “ordinary,” “medium-sized,” “moderately colored,” “moderately colorful,” and “little exciting” by users in terms of visual environmental perception. In particular, the fact that the buildings with four different functions (justice palace, government mansion, vocational school, and KYK dormitory) were designed with similar forms, symmetrical plans, and Seljuk period architectural elements created a sense of formal repetition rather than spatial diversity.

The comparative evaluation between the buildings revealed how the users perceived the design of public buildings with different functional identities and similar architectural representations in terms of spatial perception, aesthetic evaluation, and functional distinguishability. While the Palace of Justice stands out as a building where traditional architectural elements are used more prominently, the Government House and the Vocational School were evaluated by the participants in a relatively more contemporary style. This shows that although the formal language of the buildings is generally similar, user perception can differ in the level of detail. KYK Dormitory, on the other hand, was evaluated in an integrated perception plane with the other buildings due to its formal similarities despite its functional separation. Design preferences such as symmetry, entrance emphasis, façade elements (motifs such as arches, crown gates, Seljuk star), and color scale observed in all buildings provide spatial continuity but limit the level of distinctiveness. Approximately one-third of the participants stated that this architectural similarity creates difficulty in perceiving the functional differences between the buildings. This finding points to the importance of balancing formal integrity and functional legibility.
In this context, the following suggestions can be developed in line with the findings obtained:

- Architectural Diversity: Designing public buildings with different functions and architectural approaches within the same urban fabric will increase perceptual diversity and distinguishability. Differentiating each building to reflect its functional identity in architecture will enrich the user experience.
- Local Context and Identity: The local architectural elements, climatic conditions, and social fabric of Patnos should be considered in the design of the buildings. Thus, public buildings that contribute to the city's identity and are integrated with the place can be created.
- User Experience-Oriented Design: Not only aesthetics but also the impact of the design on the user (such as excitement, belonging, and creating memories) should be taken into consideration. The fact that the participants did not find the buildings "exciting" shows the weak user-place relationship.
- Strengthening Public Facades: The facade design of public buildings should be considered not only as an aesthetic shell but also as faces that reflect the public function and are open and inviting to the public.

In conclusion, it is observed that the formal similarities observed in the Patnos example have effects that may damage the urban identity, banalize the spatial perception, and weaken the user-space interaction. Developing design decisions for future public buildings with an approach that focuses on diversity, context, and user experience will contribute to creating quality urban environments.

For people to perceive and make sense of their surroundings, it is necessary to create urban spaces with qualities that can touch the user's world of meaning. In order to design quality urban spaces, it is necessary to identify the deficiencies in the current situation. This study aims to determine the current relationship between users and public buildings. It is hoped that the data obtained will guide the identification of missing points and areas to be intervened.

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User satisfaction after pedestrianization in Trabzon Kahramanmaraş Street

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Abstract. Cities are holistic formations with the spaces they host and the users they serve. Within this formation, the change of any phenomena in question causes the other to transform. In this context, today's cities are areas where transformation is on a large scale under the influence of time. Increasing population and user diversity cause different needs to arise in cities and the change in the use of urban spaces. City centers are the places most affected by this situation. City centers, which have to balance pedestrian and vehicle traffic, also try to provide certain functions and needs for their users. However, with the increasing population and densely built areas, leaving streets that cannot carry these loads simultaneously to pedestrians only, i.e. pedestrianization, is on the agenda. To what extent the pedestrianized streets meet the user's needs is a matter of curiosity. In this context, the study aims to measure the satisfaction of pedestrianization applications held to meet pedestrian circulation and user needs. So Kahramanmaraş Street of Trabzon is the study area pedestrianized in 2022. Kahramanmaraş Street, one of the prominent arteries of Trabzon city center, has undergone many transformations throughout history, from street width to ground material, from the buildings it hosts to the way of use, depending on the needs. In the study, we used quantitative methods to define the problem, and the questionnaire form was the data collection technique. The survey was conducted between December 2022 and February 2023. We also received assistance from on-site detection, observation, and photography techniques. In the study, we defined the theoretical framework by addressing the issues of space-urban space and pedestrianization and the change/transformation of the study area, and we explained the findings obtained from the survey form and interpreted the results. As a result of the study, we concluded that the users were generally satisfied with the pedestrianization of the street; however, they were not pleased with the number of facilities, planting, signs, and information.

Keywords: Urban space; Pedestranization; User satisfaction; Kahramanmaraş Street

1. Introduction

Space is not a purely physical formation, independent of the actions that take place within it or the organization caused by the user's desires and needs. It hosts daily life practices in particular, and these practices and the user framework are shaped. Therefore, as a living organism, it is in a state of change and transformation. This transformation takes place depending on time, environment, needs and expectations, and the space constantly renews itself to the extent of the possibilities of the period in which it exists.

When space is considered on a larger scale—such as the city—urban spaces emerge as areas where transformation is most visibly manifested. According to Bayrakçı, urban space consists of a set of interrelated systems; a change in any one of these systems inevitably impacts the others, resulting in the continuous evolution of the urban environment (Bayramoğlu & Özdemir, 2012). Comprising various open and enclosed spaces, urban areas serve as social connectors that bring together individuals from diverse social and economic backgrounds, fostering a sense of integration (İnceoğlu, 2007). In this context, streets, avenues, squares, and parks can be cited as examples of urban open spaces.

Urban open spaces are multi-functional environments that must accommodate a variety of uses due to the diversity of their users. In this context, such spaces can be defined as shared-use environments equipped with specific features, shaped by the social, cultural, physical, and psychological needs of individuals. Therefore, they should be designed to fulfill users' expectations and respond to needs such as rest, recreation, and transportation.

The most basic priority for the creation and maintenance of a successful urban open space is to meet people's needs and preferences. These needs can be listed as comfort, relaxation, passive and active occupation, exploration, and entertainment (İnan, 2008). The need for comfort is related to the presence of comfortable seating areas in the space, protection against external factors such as sun and wind, and good guidance within the space. The need for

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relaxation is related to providing psychological relief for people by providing water and plant covers in the space, while the need for passive occupation includes the user being able to watch the view and the activities around them (shows, sports, etc.). The need for active occupation is the user's physical participation in the activities around them. The need for exploration is the user watching and being drawn to the users, space, and spatial facilities around them, while the need for entertainment is related to the user having fun in the space and actively using that space (İnan, 2008). For this reason, it is important to organize urban open spaces (streets, avenues, landscape areas) that cannot meet current needs due to increasing population and dense construction in a way that will provide their functions, expectations, and user satisfaction.

Urban open spaces have undergone numerous transformations over time due to social, economic, and technological factors. The widespread adoption of motor vehicles, driven by the Industrial Revolution, has significantly impacted the transformation of urban open spaces and the streets within them. The presence of motor vehicles in urban spaces has transformed urban spaces that are essentially unstructured and allow human use into a structure that is structured but restricts human movement and freedom. Vehicles found in urban open spaces have been effective in the formation of pollution, dust, and noise, reduced the sustainability and quality of urban life, and destroyed the naturalness of people's living environments (Aliyev, 2021). In addition, urban open spaces have become vehicle-first places, restricting pedestrian movement and use, bringing the primary user to a secondary position, and causing the environment to be shaped in an unqualified way. Restoring urban open spaces that fail to meet the needs of city residents, ensuring cultural continuity and social sustainability, and enhancing the vitality of the city through pedestrian-focused design have become key priorities. In this context, the widespread use of urban open spaces, heavily used streets with high pedestrian movement, and the implementation of pedestrianization and their functioning as public open spaces to meet the various needs of the citizens have increased (Koçan & Rüzgar, 2016; Ateş et al., 2021). However, determining the extent to which these streets meet user satisfaction and contribute to their long-term sustainability following pedestrianization is a critical issue that requires attention. In this context, the study aims to assess user satisfaction levels regarding the pedestrianization efforts implemented to adapt to contemporary needs and conditions. The study's sample area is Kahramanmaraş Street, located in the city center of Trabzon, which was closed to traffic and pedestrianized in 2022.

1.1. Pedestrianization Concept, Objectives and Benefits

Urban spaces exist for people, while vehicles are merely tools for transportation. When considering an urban space, priority should be given to people, specifically pedestrians (Cebeci & Çakılcıoğlu, 2001; Gökgür, 2008; Aliyev, 2021). In this context, the concept of pedestrianization arises. Pedestrianization is defined as the transformation of roads (such as avenues, streets, etc.) in urban areas into pedestrian-only zones or the allocation of larger spaces for pedestrians through various modifications (Ateş et al., 2021). However, pedestrianization should not be understood merely as the creation of pathways where vehicles are restricted. Instead, it should involve the design of spaces that encourage pedestrian movement and activities, highlight human elements, and ensure controlled access and movement of vehicles (Brambilla & Longo, 1977; Ateş et al., 2021).

Pedestrianization increases livability, especially in city centers and urban open spaces, ensures the safety and easy circulation of pedestrians, and brings economic vitality to the region depending on the increase in the use of the streets and avenues where it is applied. In this regard, the pedestrianization of streets can be seen as a human-centered approach that prioritizes the public interest (Semerci & Hayırlıoğlu, 2016). Pedestrianization practices, which increase the mobility of pedestrians within the spaces they are in and improve safety, basically serve three purposes. These are to revitalize commercial areas that contribute to the regional economy, revitalize the city center, and produce spaces where people can rest, benefit culturally, and socialize (Brambilla & Longo, 1977; Dursun et al., 2021). If we need to summarize the objectives of pedestrianization in line with these purposes, these are (Dursun et al., 2021): to ensure communication and socialization; to regulate the microclimate effect; to revitalize the city center; to control the density that may occur in the city center; to reduce the use of private vehicles and to regulate traffic; to support trade and local tradesmen by making arrangements that will stimulate tourism. Some of the criteria required to achieve these goals are classified as follows (Gültiken, 2010):

1. Connection-Accessibility: It is related to the accessibility of the area at both local and urban levels.
2. Connection to other means of transportation: It is related to the connection with buses, metro, etc., vehicles within the area, or access to the area.
3. Land use diversity: The success of a pedestrian space is directly related to its ability to create a series of activities suitable for a wide variety of users. The pedestrian space should be fun, comfortable, and safe with walking areas.
4. Security, Traffic, and Social Crime: In order for pedestrian areas to become safer and more secure, there should be sufficient lighting in these areas and police officers should be on duty.
5. The quality of the walking area: Material, landscape, signs, and guides, the quality of the design, and the durability of the building materials are the main elements in the success of a pedestrian space.
6. The design and content of the walking area: Permeability, spatial definition, landscape, etc.

In line with these criteria, pedestrianized spaces (streets, avenues, etc.) must be accessible and connected to transportation networks, with vehicles allowed to enter when necessary. Security and control measures should be implemented for users, and the spaces should include certain amenities based on user needs (Gültiken, 2010). It is crucial that the amenities within pedestrianized spaces do not obstruct user movement and facilitate interaction with other users. There are certain physical elements in pedestrianized spaces affect pedestrians' perception of the space, the way they use it, and their desire. These factors include pedestrian-vehicle connections, building (facade) heights, facade lengths, flooring materials, landscaping, lighting, and urban space furnishings.

Urban space accessories are plants landscape elements and street furniture. Street furniture can be listed as; seating units (benches, tables, and chairs), bicycle racks, poles, flower beds, buffets, food and beverage kiosks, newspaper stands, parking meters, public art elements, street signs, roof elements, traffic and park signs, trash cans, lighting elements (Steiner & Butler, 2007). Among urban space amenities, seating units (such as benches and chairs) are arguably the most influential elements in shaping the use of streets. Gehl (2011) emphasized that the activities facilitated by public spaces are crucial for their quality, and seating units support a variety of activities—such as eating, reading, playing chess, sunbathing, people-watching, and conversing—that enhance the attractiveness of these spaces.

Plants and landscape elements found in urban open spaces and streets have positive effects on human psychology. With these effects, plant landscape elements create a natural ground for people to stop, rest, and chat, and contribute to users' socialization and use of the space. In addition, plants reduce heat access by acting as a shader in urban open spaces and streets; balance the microclimate of the space by allowing heat to spread throughout the space, and provide noise, dust, and sound insulation by acting as a screen between vehicles and pedestrian spaces (Emmanuel, 2005; Tandoğan & Şişman, 2018).

Additionally, in urban open spaces, it is essential to design food and beverage areas to enhance user satisfaction and transform the space into a place where users can relax, rather than merely walk. Providing various activities and shops in pedestrian areas are crucial elements that attract users to this place. Lighting elements and information boards should be mounted on the walls, and signs and directional signs should be brought together in a single structure as much as possible. Appropriate materials should be chosen for road pavements, ensuring that the selected materials are non-slippery. In addition, the flooring material should allow for comfortable walking, and the patterns created on the flooring should be arranged in a way that guides the user. (Koç & Sönmez, 1996).

As a result, the most crucial factor in effective design is addressing human needs. In the renovation or redesign of existing open spaces (such as the pedestrianization of streets), creating a successful space requires observing users and investigating their needs. Organizing and designing open spaces based on user needs is one of the key factors in the success and development of these spaces (İnan, 2008).

2. Materials and method

The study area is Kahramanmaraş Street, one of the three main access arteries in the city center of Trabzon. The street was selected as the study area because it has witnessed the physical and historical development of the city, holds an important place in the city's collective memory, has been recently pedestrianized, and experiences high user density. This study examines the pedestrianization of Kahramanmaraş Street from the users' perspective and its impacts on user experience. Data were collected using a structured questionnaire administered to 233 users who had experienced the street both before and after pedestrianization. The survey was conducted between December 2022 and February 2023. The questionnaire consists of 53 questions covering demographic characteristics, user evaluations following pedestrianization, satisfaction levels, and expectations. Of these, 44 questions use a 5-point Likert scale, where "1" corresponds to "strongly dissatisfied" and "5" corresponds to "strongly satisfied". The semantic interpretation of the average scores is as follows: 1.00–1.80: very low; 1.81–2.60: low; 2.61–3.40: medium; 3.41–4.20: high; and 4.21–5.00: very high.

2.1 Study area: Kahramanmaraş Street

Kahramanmaraş Street starts from Meydan Park and extends to the Ayasofya Neighborhood. Considering the length of the street and its location in the city center, it is one of the most important axes connecting the city of Trabzon horizontally. The pedestrianized part of the street is limited to the area between Gazipaşa Street and Cumhuriyet Street.

When we examine the historical development of Kahramanmaraş Street, one of the key landmarks in the city's collective memory, it is evident that the street has undergone several transformations. During the Russian occupation between 1916 and 1917, a 'middle street' was planned to extend from the Hagia Sophia Neighborhood to Meydan Park for military purposes, specifically to transport ammunition. Subsequently, the street, which came to be known as 'Russian Street,' was renamed 'Kahramanmaraş Street' during the War of Independence (Üstün Demirkaya, 2014; Tuluk & Bayrak, 2019). When initially constructed, the street was narrower and lined with densely packed wooden houses, which were expanded upon by the Russians (Doğan, 2009; Dinçer, 2016). It is known that Turkish neighborhoods and houses belonging to Turks were primarily located along this street, and many buildings were demolished during the expansion (Çapa & Çiçek, 2004; Düzenli, 2009).

When considering the pedestrianized section of the street, several historical buildings stand out (Fig. 1). The first of these is the Ziraat Bank building, which opened in 1950. It is said that the smooth-surfaced stones used in its construction were sourced from the remains of a church that previously stood on the bank's site (Düzenli, 2009). During this period, another important structure from the Republican era, the old Central Bank, was built adjacent to the Ziraat Bank (Düzenli, 2009). Today, the building houses the 'Trabzon City Museum.' At the eastern end of Kahramanmaraş Street stands the Meydan Hamamı, which was built in the late 19th century (Horuluoğlu, 1978). The building features an entrance to the women's section from the side street, while the men's section is accessible from Kahramanmaraş Street (Üstün Demirkaya, 2014).

The Zorlu Grand Hotel, located on the street, is another significant structure that holds a prominent place in the city's memory. Built in the 1990s, it was the first 5-star hotel in the city and the surrounding region (URL-1, 2025) and continues to operate today. In addition to these landmarks, the street is home to numerous private and state-owned banks, business centers, offices, buffets, exchange offices, florists, stores, hairdressers, sales units, food and beverage venues, and educational facilities, all serving the city's residents with a wide range of functions and scales. Due to the high concentration of banks, the street is also commonly referred to as 'Banks Street' by the public (Fig. 1).

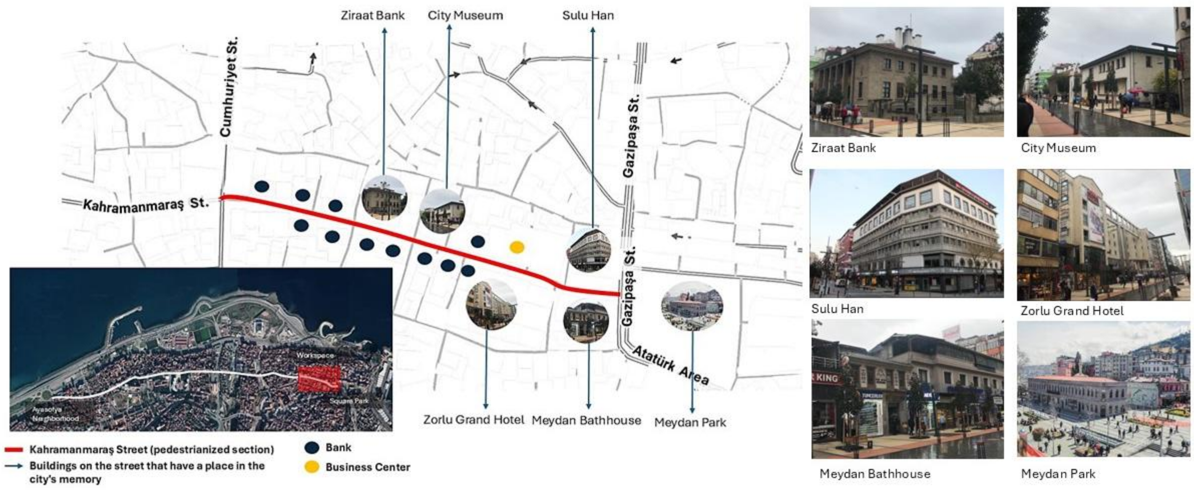

Fig. 1. Kahramanmaraş Street from Hagia Sophia to Meydan Park

In the 1930s, Kahramanmaraş Street had a dirt surface, but by 1950, it was paved with roughly cut Trabzon stone in cobblestones, a texture that remained intact until the pedestrianization works. The sidewalks were originally made of concrete and were later paved with concrete slabs in 2007-2008 (Doğan, 2009). In 2022, the entire street surface was covered with a rubber material as part of the pedestrianization efforts. However, due to issues with the flooring material, the surface was renewed in 2023 (after the survey study) with asphalt, which was poured and painted (Fig. 2).

Fig. 2. The situation of Kahramanmaraş Street in the 1980s (Dinçer, 2016); 2021- The situation of the street before pedestrianization (URL-2, 2025), 2022; The situation of the street after pedestrianization (URL-3, 2025)

According to the Lambert Plan, Kahramanmaraş Street, which is considered the backbone of the city, served two-way vehicle traffic until 2010. In 2010, vehicle traffic changed to one-way. Due to the density of the city center and the increase in the human population, the street was completely closed to traffic and pedestrianized in 2022, and it was opened to service by adding certain urban facilities within the scope of pedestrianization.

2.2. State of Kahramanmaraş Street after the Pedestrianization in 2022

The Trabzon Metropolitan Municipality Transportation Department Transportation Coordination Center (UKOME) decided to pedestrianize Kahramanmaraş Street with Decision No. 2021/068, dated 04.10.2021. In line with this decision, the street was pedestrianized in 2022, new functions were created, and various urban facilities were added. The implemented improvements can be categorized under the headings of 'seating elements,' 'lighting elements,' 'trash cans,' 'borders,' 'planting and trees,' 'floor arrangement,' 'accessibility,' and 'bicycle and electric vehicle accessibility'.

Seating elements: There were no seating elements on the street before pedestrianization. Following pedestrianization, seating, and resting elements were introduced to support activities such as resting, waiting, and observing the surroundings. Three different types of seating elements have been installed throughout the area (Fig. 3).

Fig. 3. Seating elements

Lighting Elements: The lighting elements on the street are positioned along the edges of the central axis allowing occasional vehicle access. They are arranged in four different ways based on the direction of the light. Although their positions are almost the same as before pedestrianization, there has been a noticeable improvement in their aesthetic quality (Fig. 4).

Fig. 4. Lighting elements

Trash Cans: Two different types of trash cans are present on the street. The first type is a lidless trash can, made of similar materials and placed next to the lighting elements. The second type is a larger, lidded trash can with underground recycling bins. The trash cans integrated with the lighting elements are consistent with the design form used before pedestrianization; however, the use of wood as a material adds aesthetic value to the design (Fig. 5).

Fig. 5. Trash cans and borders

Borders: After the pedestrianization of the street, it became necessary to create a separation between pedestrian and occasional vehicle use to accommodate limited vehicle access when required. In this context, the road on the street, which provides vehicle access when necessary, and the area with seating elements and trees (the area reserved for pedestrian use only) are separated by bourder elements. Before pedestrianization, the separation between pedestrian and vehicle areas was achieved only through the pavement and roadway arrangement. In terms of design, the border elements used after pedestrianization are of a single type but vary in size (Fig. 5).

Trees and Plants: Before pedestrianization, there were a limited number of trees on the street. After pedestrianization, the number and diversity of trees and plants increased (Fig. 6).

Fig. 6. Trees and Plants

Floor Arrangement: Before pedestrianization, the street consisted of a cobblestone roadway and concrete pavements. Following pedestrianization, the areas designated for seating elements were covered with rubber flooring material, while the sections intended for occasional vehicle use were paved with cobblestones. An aesthetic appearance was created by using different colors in the floor covering materials (Fig. 7).

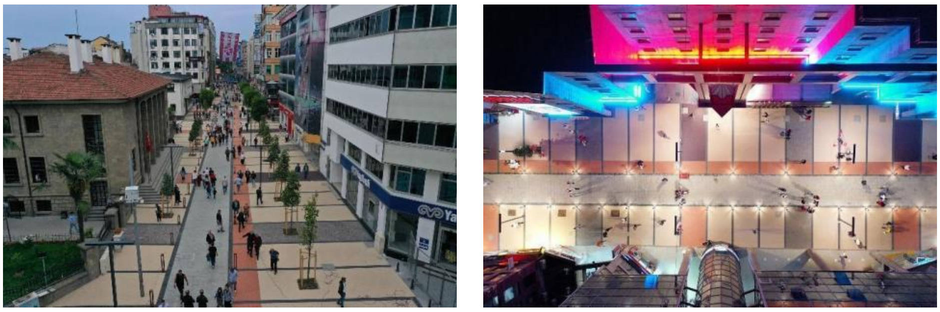

Fig. 7. Floor arrangement in 2022 (URL-3, 2025)

Accessibility: Before the pedestrianization of the street, a level difference was created through pavement arrangements to separate pedestrian and vehicular access areas. While this posed challenges for accessibility for disabled individuals, the inclusion of tactile surfaces in the pavement provided some advantages. In the new layout implemented after pedestrianization, the absence of level differences offers improved accessibility for disabled users. However, the new ground arrangement lacks tactile surfaces for individuals with visual impairments (Fig. 8).

Fig. 8. Floor arrangement without tactile surfaces

Bicycle and Electric Vehicle Accessibility: Before pedestrianization, there were no bicycle or electric vehicle paths on the street. Following the pedestrianization, a designated bicycle path was added. However, the beginning and end of this bicycle path, located in a specific section of Kahramanmaraş Street, are not connected to any other routes. Additionally, parking areas for electric vehicles have been established along the street (Fig. 9).

Fig. 9. Bicycle paths and parking areas reserved for electric vehicles

2. Results

An evaluation of the general demographic information of participants who experienced the street revealed that 67% were female, 33% were male, 31% were young adults aged 19-25, and 29% were adults aged 46-60. Regarding educational status, 65% of participants were university graduates, and 25% had completed high school. Additionally, 36% of street users were students, 26% were housewives, and 21% were civil servants (Fig. 10).

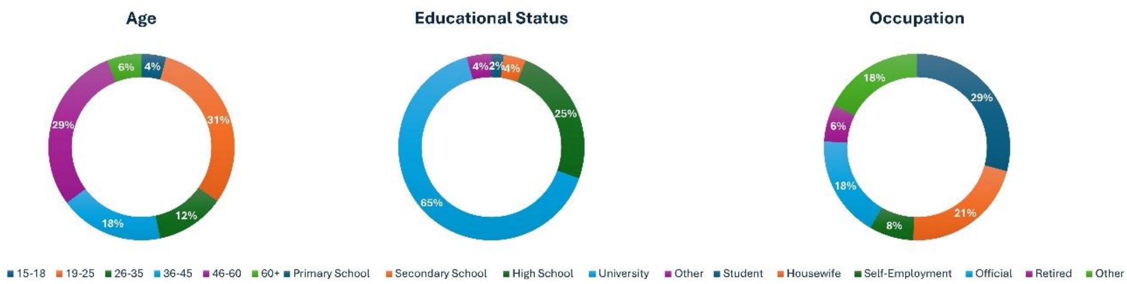

Fig. 10. Age, educational status and occupation of participants

When the frequency of use of the street during the day was evaluated, it was seen that 41% of the users used Kahramanmaraş Street once a week, while 19% experienced the street every day. The purpose of the users using the street during the day was mostly walking and passing 48%, sightseeing (44%), and the other frequently preferred purpose of use was shopping (38 %) (Fig. 11).

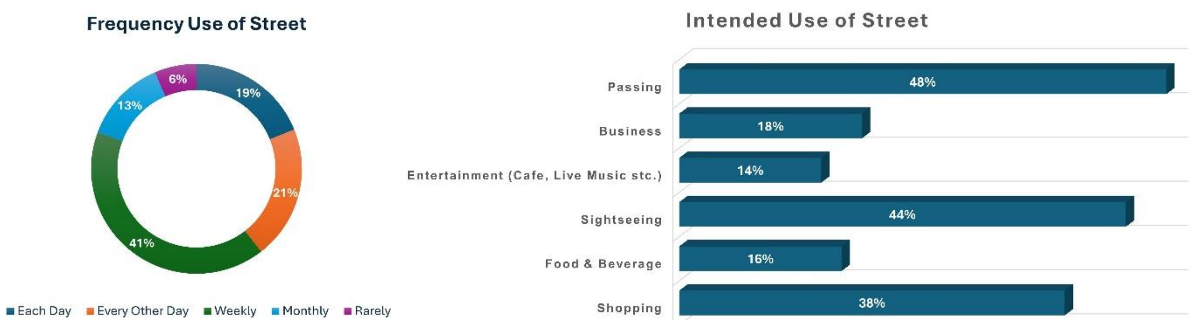

Fig. 11. Distribution of frequency use of street and intended use of street

When participants were asked about the frequency of street use at night, it was found that nighttime usage was lower than daytime use. The majority of users stated that they rarely visited the street (52%) at night. The purpose of using at night was mostly for passing (59%), followed by sightseeing (33 %) and the use of entertainment venues (16 %) (Fig. 12).

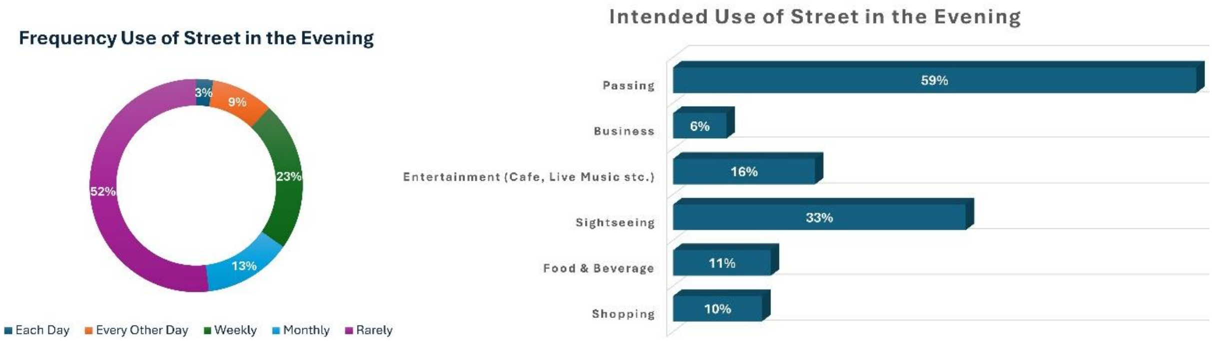

Fig. 12. Distribution of frequency use and intended use of street in the evening

Participants were asked to evaluate their satisfaction with the current state of Kahramanmaraş Street, specifically focusing on the effects of pedestrianization. As reflected in the responses to the proposition 'I am satisfied with the pedestrianization of the street,' participants reported a very high level of satisfaction (4.48) (Fig. 13).

Fig. 13. User satisfaction status after pedestriazination

To further assess their overall satisfaction, participants were asked to indicate their level of agreement with various statements regarding the use of the street. The findings show that users strongly agreed that the street allows for more comfortable walking after pedestrianization (4.4), that pedestrian safety has improved (4.33), and that accessibility for the elderly, disabled individuals, and strollers has increased (4.3). Participants also agreed that the street has become more suitable for night use (4.13), that the urban environment is better perceived and shop windows are more easily viewed (4.12), that the street has become a center of attraction for the city (3.87), that noise and environmental pollution have decreased (3.83), that the frequency of street use has increased (3.61), and that participation in social and cultural activities has risen (3.67). The lowest level of agreement was observed for the proposition that 'closing the street to traffic did not negatively affect transportation' (3.5). Overall, a review of all propositions reveals a high level of satisfaction, indicating that users' experiences after pedestrianization are significantly more positive compared to their experiences beforehand.

An evaluation of user satisfaction with the street layout, flooring, seating elements, lighting elements, and trash cans within the scope of the pedestrianization project on Kahramanmaraş Street revealed a medium level of agreement with the related propositions, with an average score of 2.88. It can be concluded that users reported a medium level of satisfaction with the separation of sitting and walking traffic (3.36) and with the organization of movement directions (3.16) on the street. Similarly, the suitability of the street's post-pedestrianization layout for electric vehicles (3.19), the sufficiency of the number of signs and signboards (3,02), and its aesthetic condition (2.91) were the situations where the users had a medium level of satisfaction. It is seen that the responses of the participants to the propositions of the suitability of the bicycle path on the street for use (2.32) and the sufficiency of trees and planting (2.59) indicated a low level of satisfaction (Fig. 14).

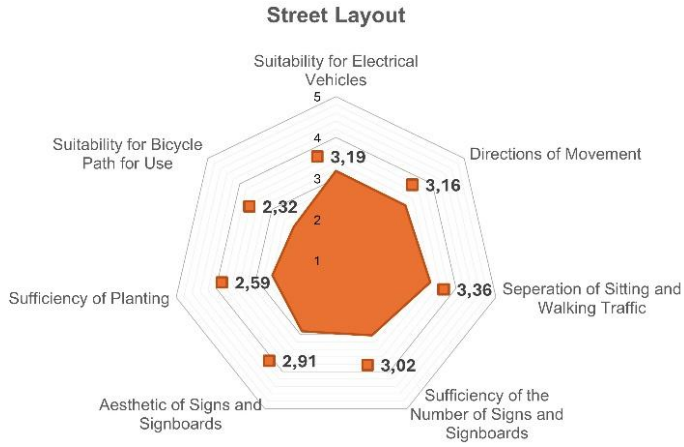

Fig. 14. Satisfaction status with street layout and related criteria

Participants' evaluations of the flooring qualities following pedestrianization indicated a moderate level of satisfaction, with an average score of 2.86 (Fig. 15). We can conclude that the participants found the suitability of the flooring for the elderly and disabled individuals (3.3), its functional suitability (2.87), and its aesthetic status (3.17) to be at a medium satisfaction level. Accordingly, participants' appreciation of the flooring was at a medium level (2.9), while their satisfaction with its durability and longevity was low (2.25). The fact that the flooring had to be replaced due to wear shortly after the pedestrianization project finished supports this result.

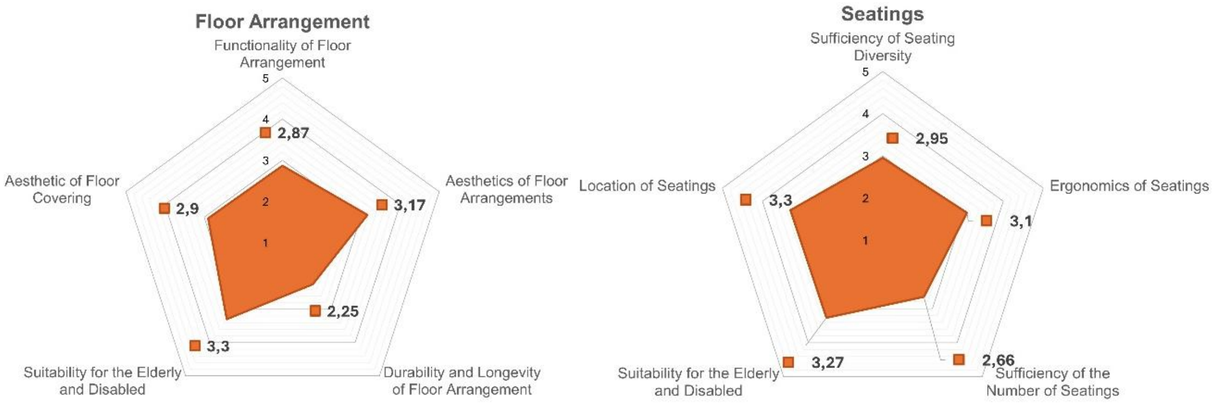

Fig. 15. Satisfaction status with floor arrangement and seating elements

When Seating elements are one of the urban facilities added after the pedestrianization of the street. An analysis of participants' responses regarding the seating elements on the street revealed a moderate level of satisfaction, with an average score of 3.02 (Fig. 15). The ergonomic quality of the seating elements (3.1), their location (3.3), and their suitability for seniors and individuals with disabilities (3.27) all received medium satisfaction scores. When asked about the adequacy of the seating elements, participants reported a moderate level of satisfaction with the variety available (2.95) and a low level of satisfaction regarding their quantity (2.66). In this case, we can say that the participants found the seating elements insufficient in number.

Researchers asked questions regarding the lighting elements whose design and number changed within the scope of pedestrianization on Kahramanmaraş Street, we observed that the answers were at a high (3.62) satisfaction level (Fig. 14). Participants evaluated the functionality (3.68), adequacy in number (3.81), location (3.72), and aesthetic status (3.56) of the lighting elements at a high satisfaction level. In addition, participants had higher satisfaction with the lighting elements not hindering walking (3.6). Based on the answers to the questions asked to users about the number and location of the trash cans along with the urban facilities added after pedestrianization, we can say that the general satisfaction level of users regarding the trash cans was at a medium level (3.2). Users were moderately satisfied with the adequacy in number (3,07), location (3.33), and aesthetic status (3.25) of the trash cans added to the street. Participants had a high (3.6) satisfaction level with the functionality of the trash cans (Fig. 16).

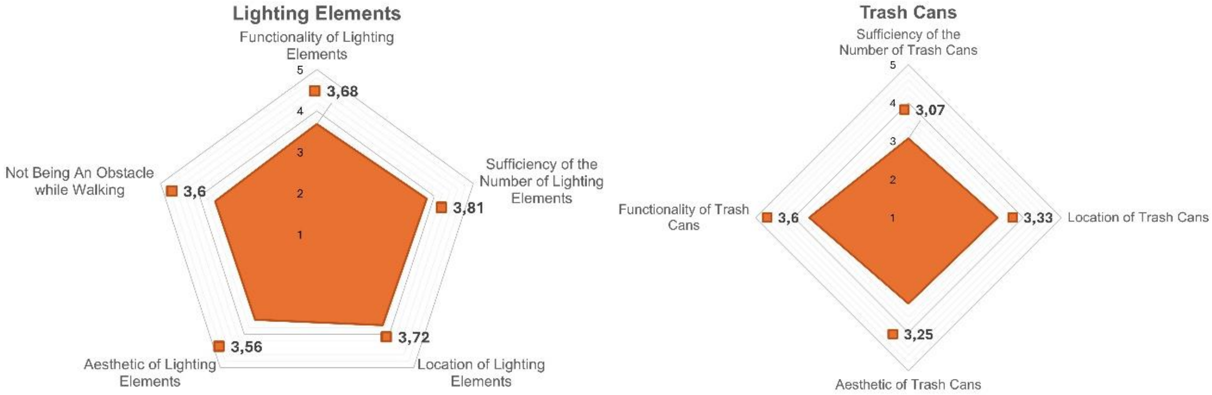

Fig. 16. Satisfaction status with lighting elements and trash cans

As a result of the evaluation carried out to determine user expectations, we can say that users highly want specially designed buffets, bagel shops etc. sales units on the street (3.94), more social spaces such as eating and drinking, and resting on the street (3.93), monumental elements such as works of art and sculptures on the street (4,05), and water elements on the street (3.75) (Fig. 17). In addition, participants stated that they highly want more cultural spaces on the street (4.3) and planned/programmed events to be organized on the street (4.3).

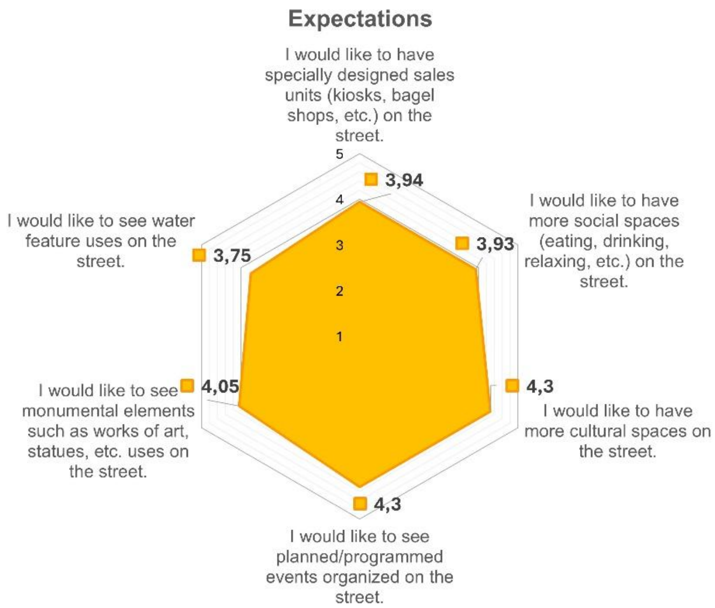

Fig. 17. Expectations for the future arrangement of the street

Thirty-one participants responded to the question regarding additional opinions they wished to share following the pedestrianization of Kahramanmaraş Street. Eleven participants highlighted problems with the ground covering, citing issues such as rapid material wear, poor aesthetic quality, slipperiness during rain, and inconvenience for elderly users. Nine participants suggested that the street should be socially and culturally enriched by incorporating elements such as spaces for street performers, cafés and kiosks, children's playgrounds, libraries, opportunities for selling local food, and architectural features that reflect the city's identity.

Three participants emphasized the need to increase the number of trees and green spaces, and another three pointed out the lack of functional zoning in the street layout, noting that seated individuals often obstruct pedestrian flow. Two participants indicated that pedestrianization had been implemented without adequate consideration of the broader urban transportation system. Additionally, two participants recommended relocating and increasing the number of trash bins. Two others stressed the need for a clearly defined bicycle path, while one participant requested the installation of tactile surfaces and a security point.

3. Conclusion

Transforming urban open spaces to meet user needs is important for the sustainable and human-centered development of cities. In this respect, the study aimed to evaluate Kahramanmaraş Street, located in the city center of Trabzon and pedestrianized in 2022, regarding user satisfaction, physical characteristics, and responsiveness to expectations. The findings show that the pedestrianization application was generally welcomed positively by users and provided a high level of satisfaction.

In terms of frequency of use, the rate of individuals using the street every week is high, whereas night use is more limited due to factors such as safety and functionality. Social and individual activities such as walking and shopping are at the forefront during the day and transition at night. Users are particularly pleased with the arrangements that address basic needs such as increased pedestrian safety, improved accessibility, and increased walkability. In addition, contributions to the street becoming a more attractive urban space and encouraging social/cultural interaction affect the satisfaction levels with pedestrianization. On the other hand, users have made a reserved assessment regarding the effects of the street being closed to vehicle traffic on transportation systems.

Regarding physical arrangements, elements such as the street layout, seating areas, flooring, and urban amenities like trash cans generally achieved moderate satisfaction levels. Notably, the flooring received low ratings concerning aesthetics and durability, highlighting the need for improvement to ensure the sustainability of pedestrianization. Although the placement of seating elements was positively evaluated, the number of seats was deemed insufficient. Conversely, lighting elements achieved high satisfaction levels in terms of both aesthetics and functionality. Meanwhile, low satisfaction regarding planting arrangements and bicycle paths indicated deficiencies in making the street a more livable and multifunctional urban open space. Similarly, the inadequacy of directional and informational signage emerged as another area needing attention to enhance usability.

Findings concerning user expectations revealed a strong demand for the addition of social, cultural, and artistic elements along the street. Features such as planned events, cultural venues, water elements, and monumental artworks have the potential to strengthen users' emotional and functional bonds with the space.

Overall, the pedestrianization of Kahramanmaraş Street has made significant contributions to increasing opportunities for socialization, rest, and urban interaction, sustaining the vibrancy of the city center, and improving the quality of public life. The initiative has largely succeeded in adhering to fundamental pedestrian-oriented principles and achieving high levels of user satisfaction. Nevertheless, further improvements in areas such as physical design quality, landscape diversity, wayfinding systems, and the adequacy of social facilities will enhance the space's sustainability and its contribution to urban life quality. Due to wear, deterioration, and negative user feedback, the street's flooring was renewed in 2023 shortly after its initial use, and tactile paving applications were introduced in 2024. This situation underscores the importance of accurately identifying user profiles and needs, and continuously responding to emerging demands and improvements based on usage patterns. Otherwise, it is undeniable that a space unable to satisfy its users cannot maintain its vitality. It can be concluded that Kahramanmaraş Street, an important axis in the city's urban memory, will continue to evolve into a higher-quality public space through a holistic planning approach that remains sensitive to user needs.

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Evaluation of Karadeniz Technical University Kanuni Campus with universal design criteria

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Abstract. The concept of universal design is a holistic design approach that provides solutions for different user groups. The main purpose of space designs based on universal design principles is to create spaces that will perfectly meet the needs of all users according to their characteristics. Spaces designed with this understanding; It should offer opportunities that individuals with different characteristics can easily access, use, act independently and benefit from all kinds of social activities. Accessibility is a necessary prerequisite for ensuring equal conditions for everyone in the built environment. Today, many urban areas are not accessible to disabled people. Like every individual in society, disabled individuals should be able to benefit from public spaces equally. In order to prevent the problems that disabled people encounter in the use of space, universal design criteria for disabled people should be followed. It is the fundamental right of disabled individuals to have access to university campuses and to have unimpeded movement within the campus. The accessibility of university campuses should comply with universal design principles. For a holistic, inclusive and universal design, transportation to and accessibility within the campus area should be taken into consideration. The general purpose of this study is to evaluate accessibility in Karadeniz Technical University Kanuni Campus in line with universal design principles and to reveal how designs for disabled individuals can be made to increase accessibility. For this purpose, observations and evaluations will be made in the Kanuni Campus.

Keywords: Universal design criteria; Karadeniz Technical University; Barrier-free design; Barrier-free campus; Accessibility

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1. Introduction:

The 'universal design' approach, in which everyone has equal use and accessibility in the design of space, environment and equipment elements, includes different scales from urban space to in-building transport and accessibility (Tandoğan, 2017).

The main objectives of the universal design approach are to make the urban environment and the spaces within the building accessible and understandable for all users, to provide equal use and barrier-free access opportunities for all users, and to facilitate the use of built environments for disabled individuals.

Universal design, inclusive design, design for all concepts aim to make the built environment and products we live in accessible to everyone. This concept is a design concept that facilitates the life of all user groups who are not only disabled individuals but also disabled candidates at every moment of their lives. Universal design principles help to increase the level of accessibility and quality of life of individuals in their spaces and built environments.

The understanding of design for all is important in the design of urban environment, social areas and spaces with equal use and barrier-free accessibility for all individuals (Kavak, 2010). Readability, perceptibility, livability, accessibility, suitability, etc. in urban areas constitute important criteria in increasing the quality of use of public spaces (Tandoğan, 2017). It is possible for public spaces to appeal to all individuals by realising the determined criteria with appropriate solutions.

"Accessibility means that everyone can access and use any place and any service independently and safely." (Accessibility Guidelines, 2020). Accessibility includes non-discrimination, physical accessibility, economic accessibility and information accessibility (WHO, 2017). Accessibility in university campuses is also extremely important to ensure the rights, freedom and comfort of all users.(Yerli and Özdede, 2017) explains that accessibility in transportation means 'the ability of every individual to reach from one point to another point in the city without any obstacles'.

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Accessibility, when considered as the physical environment, is defined as the ability of all individuals to participate in social life without the need for others and to access public spaces and services safely. Today, in pedestrian zones located in many urban spaces, users experience problems in accessibility to physical space due to the fact that accessibility is not handled in a multidimensional way (Sandoval, 2018).

There are many legal regulations in the world and in Turkey to emphasise that every individual in society has equal rights and to protect the rights of persons with disabilities. The Universal Declaration of Human Rights, published in 1948 and signed by Turkey, emphasises that every member of society has the right to access higher education without discrimination. Adopted by the Committee of Ministers of the Council of Europe in 2001, it recommended that all professions related to the field of design should include universal design in their education and training (Boduroğlu et al, 2011). With the amendment made in the Decree Law No. 5378 in our country, problems in the field of accessibility, education and health have been addressed, and the regulations made in a wide scope in these places are included (Gören, 2018).

Disability is a limiting and restrictive impairment of an individual's life activities, abilities and strength (Öztabak, 2017). Design and planning principles for persons with disabilities should enable equal use of space. Simple, flexible, perceptible, comprehensible, comprehensible, hazardous, easy and comfortable spaces should be designed for the skills and wishes of disabled people (Ökten, 2018). The prejudices brought by the lack of awareness in the society and the fact that the physical environment is not designed in a way suitable for the use of disabled people cause the disabled to be excluded from the society (Çınar, 2010).

In the built environment, the understanding that designs are generally made for average user groups (general) (Tutal, 2018) reveals the situation that not all users can benefit equally from the built environment and causes disability (disability) problems. In other words, the disability is not caused by the user but by the environments as a result of the designs. Disability is diverse and accessibility is expected to be inclusive.

Accessibility is the state of being accessible to the outside world, and disability is the state of being hindered by the outside world and the loss of abilities. In other words, accessibility is an important quality indicator in public urban space (EPOA, 1997), (İnceoğlu, 2007). In the discipline of architecture, accessibility can be defined as the quality of easy access to the environment and spaces (Sandoval, 2018).

1.1. Purpose and method of the research :

The aim of the study is to evaluate the usability of Karadeniz Technical University (KTU) Kanuni Campus (central campus) by disabled students within the scope of design for all understanding and to make suggestions to improve the current accessibility level in line with universal design principles.

The focus was on determining the physical accessibility levels for pedestrian roads, pavements and public spaces that provide access between spaces. The concept of accessibility has been handled at the campus scale, and the measures to be taken for accessibility have been evaluated with a holistic approach.

Within the scope of the research, a conceptual framework was created by reviewing the literature, and documentation was provided by on-site observation and photography method in KTU Kanuni Campus, which was determined as the research area. With the data collected, the compliance of the public open spaces on the campus with universal design principles was evaluated and solutions were proposed for the problems identified.

1.2. Universal design (Design for everyone):

Universal design (Design for everyone) is the design of products, services and the built environment so that they can be used by as many people as possible, regardless of age or ability (Koca and Yılmaz, 2017).

The main objectives of the design for all approach are to ensure that spaces and products are accessible, accessible, appealing to a large audience and realising designs with general use. Universal design, as a design that is equally accessible and usable without discrimination, aims to provide physical harmony, easy perception of the environment and reduce energy costs (Hacıhasanoğlu, 2003).

Universal design is an approach that meets the needs of different users and offers solutions without grouping them or creating physical difficulties. Universal design is not just about people with disabilities having the same rights as other users in society. It aims for equality for all users, whether disabled or not. Usability, accessibility and inclusiveness form the basis of the universal design philosophy (Yılmaz, 2022).

The aim of universal design is for everyone in society (children, elderly, disabled and non-disabled, etc.) to benefit equally from the services offered by the space. It aims to meet the needs and expectations of different individuals and to respond to these needs equally with the same product that includes different options (Gören, 2016).

The concept of universal design can be defined as a way of proposing design solutions that meet the needs of different user groups and do not label users (Story et al., 1998). The goal of universal design is to design products and environments that are accessible to as many users as possible without requiring adaptation or special design.

Universal design, which emerged from the idea that every individual should be accessible to every object and space at all times, is a design approach that provides users with as much independence as possible, is suitable for their special needs, provides information to the user and is also sustainable (Boduroğlu, 2014).

1.3.Universal design principles:
The principles of universal design were developed by The Centre for Universal Design group at the University of North Caroline working on universal design. These principles aim to evaluate existing designs, to correct deficiencies and to educate designers and users. Universal design criteria can be explained as follows (Story et al., 1998);

- Equitable Use: The design should be such that every individual with different abilities can use and buy it, regardless of the user. (No discrimination)
- Flexibility in Use: The design should be accommodate different individual abilities and preferences.
- Simple and Intuitive Use: There should be simple, understandable designs independent of the user experience.
- Perceptible Information: The design should be able to provide the user with the necessary information independent of the environmental conditions and the different sensory abilities of the users.
- Margin of Error in Design: Design should minimise hazards and accidents and undesirable adverse effects.
- Low Physical Power Usage: The design should be able to be used efficiently with minimal effort.
- Providing Size and Space for Approach and Use: Regardless of the user's body size, limb deficiencies, different ability characteristics, appropriate size and space should be provided for the use of the design.

Usability, accessibility and inclusiveness are fundamental requirements in the philosophy of universal design. The designs of the campus environment and buildings, which contain many functions, should serve all users regardless of age, disability, or ability.

1.4.Universal design in university campuses:
In addition to education and training, university campuses include functions such as resting, eating, drinking, accommodation, sociocultural and sportive activities. These campuses should be inclusive and free spaces open to the participation of all users (Tutal, 2015).

Universities are public institutions where social awareness of people with disabilities should be at the highest level.” (Küçükali, 2014). In order to prevent social exclusion of disabled people in all spaces, especially in educational areas, the society should be made aware of disability and designs should be developed to ensure that disabled people are comfortable in social environments (Çınar, 2010).

According to the universal design approach; designing spaces that will increase the livability and quality of university campuses ensures the development of society and eliminates the problems that university students may experience on campus. It is necessary to make designs that will enable each user to access and use the campus facilities as they wish, to develop solutions to the problems encountered, and to examine this situation in the case of physically disabled people (Ökten, 2018).

For a healthy society, it is necessary to reduce the physical problems experienced by people with disabilities and to take a fair place in educational areas in order for them to exercise their most fundamental right, which is their right to education (Sevinç and Çay, 2017).

Ensuring the right to education for all is directly related to the accessibility of the built environment. In educational spaces, especially university campuses, it is extremely important that all areas and elements are accessible and usable for all individuals who make up the diversity of users. For this reason, it is an important necessity for campus designs to be holistic, sustainable and developable as well as accessible to everyone. Three important requirements that should be emphasised in terms of campus planning are safety, social participation and ‘accessibility’ (Yerli and Özdede, 2017).

The application areas of accessibility in university campuses cover a wide range of scales such as pedestrian roads, sidewalks, pedestrian crossings, gathering areas, car parks, all buildings that support education, technical and social services, transportation services, stop and waiting areas, recreation areas. This broad scale defines the physical system that connects spatial uses within a university campus. For this reason, each area should be handled carefully in a way to ensure consistency and continuity with each other.

2. Research area:

2.1. Karadeniz Technical University KTU Kanuni Campus (Central Campus):
Founded on May 20, 1955 and starting education in 1963, Karadeniz Technical University (KTU) provides education in the branches of technical sciences, science, human sciences and health sciences. The location of KTU Kanuni Campus is shown in Fig. 1

The site plan of KTU Kanuni Campus is shown in Fig. 2.

The number of students with disabilities between 2023 and 2025 is shown in Table 1.

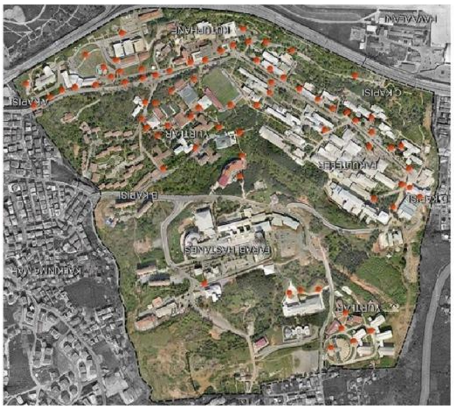

Fig. 1. KTU location

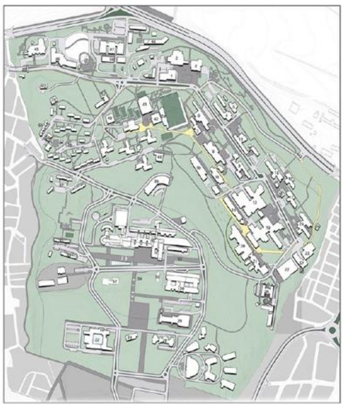

Fig. 2. Campus site plan

Table 1. Number of disabled students at Karadeniz Technical University between 2023-2025

Types of disabilities	Speech	Physical	Vision	Hearing
2022-2023	2	8	1	3
2023-2024	2	9	3	3
2024-2025	2	6	3	2

3. Research findings:

When KTU Kanuni Campus is evaluated according to universal design criteria;

- Equitable use:

There are not enough disabled parking lots on campus.

Many ATMs on campus are inaccessible for people with disabilities.

ATMs on campus are not suitable for wheelchair users (Fig 3).

There are no tactile surfaces for the visually impaired at pedestrian trails and building entrances (Fig 4).

Not all building entrances on campus are designed to be easily accessible to all user groups (Fig 5).

The building entrances of the faculties are designed in such a way that each individual can use them comfortably with a minimum of 90 cm.

Accessibility to social and sports areas within the campus is not possible in some places (Fig 6). Access to sports fields is problematic.

Fig. 3. ATMs not suitable for people with disabilities

Fig. 4. Building entrances with stairs not suitable for disabled people

Fig. 5. Building entrances with stairs not suitable for disabled people

Fig. 6. Canteen entrances with stairs not suitable for disabled people

- Flexibility in use:

There are ramps next to the stairs at the entrances of faculty buildings, administrative buildings and socio-cultural areas (Fig 7).

Except in a few places, there are no ramps to descend from sidewalks to road level (Fig 8).

There are some alternative routes on campus. Sidewalks are designed for a minimum of 90 cm.

Fig. 7. Ramps next to the stairs at the entrances of buildings

Fig. 8. Ramps to descend from sidewalks to road level.

- Simple and intuitive use:

Except for a few places, there are no parking lots reserved for the disabled.

The entrances of many buildings on the campus can be easily perceived.

There are no grab barriers on all stairs and ramp edges (Fig. 9).

None of the existing bus stops are suitable for disabled people. Bus stops do not have ramps to the sidewalk. There are no suitable seating units for the disabled at bus stops (Fig. 10).

- Perceptible information:

There are no arrangements for the visually impaired on campus. There are no guide lines on campus. Information and directional signs are of perceptible size (Fig 11).
There are no warning signs at the beginning and end points of the stairs and ramps (Fig 12).

Fig. 9. A ramp without handrail

Fig. 10. Not suitable bus stops suitable for disabled people

Fig. 11. Directional signs

Fig. 12. Stairs without warning signs at the start and end points

- Margin of error in design:

Guide tracks and embossed surfaces for the visually impaired have not been considered.
Traffic signs and warning signs are frequently placed on the roads on the campus.
Braille signs should be made available throughout the campus.
Visual warnings should be added for the hearing impaired.
There are no stimuli at the start and end of the stairs (Fig 13).

Fig. 13. Stairs without warnings

- Low physical power usage:

Ramps at the entrance of some faculties have not been solved (Fig 14).
Some entrances have narrow or steeply sloping ramps (Fig 15).
Except for one faculty, there is no lifting platform for disabled people on the stairs (Fig. 16).
There are photocell doors at the some building entrances.
A sidewalk is encountered at pedestrian crossings. (Fig. 17)

- Providing Size and Space for Approach and Use:

ATMs and ticket loading units on the campus are not suitable for wheelchair users (Fig. 18).

Bus stops are not suitable for disabled people. There are no warning signs in waiting areas and sidewalk endpoints.

Fig. 14. A Building entrance without ramps

Fig. 15. Narrow and steeply sloping ramps

Fig.16. Lifting platform for disabled people on the stairs

Fig. 17. Pedestrian path and sidewalk are not level.

Fig. 18. No ramp leading to the ATMs located on the sidewalk.

4. Conclusions

In order to make university campuses barrier-free, it is necessary to raise awareness about accessibility, identify the accessibility problems of disabled students and take measures accordingly.

The lack of continuity of pedestrian roads and their physical characteristics not conforming to the standards have a negative impact on accessibility. It is important to evaluate the pedestrian transport network and create accessibility maps.

This study reveals the problems created by the physical environment of Karadeniz Technical University Kanuni campus for disabled students. In the study, it is aimed to evaluate the accessibility of KTU Kanuni Campus (central campus) and to propose solutions to the problems identified. For this purpose; the accessibility of KTU Kanuni campus was evaluated with universal design criteria and positive and negative aspects were determined. In the university campus, campus entrances, transport links, pedestrian trails, public transport stops, car parks, public open spaces and building entrances were analysed and photographed through observation and experience.

The current ease of use and the barriers identified in terms of accessibility are presented in the research findings. Suggestions were developed for the identified negative uses.

Based on the determinations and evaluations made in the study through universal design principles, it is important to increase the accessibility of areas such as pedestrian roads, parking lots, ATMs, ramps and parking lots.

In KTU Kanuni Campus (Central Campus), it is necessary to provide or increase accessibility with solutions such as making guide tracks, providing audio and visual guidance signs, making necessary arrangements at building entrances that do not comply with the standards, adding ramps/technological solutions to buildings without ramps, adding handrails to those who need handrails on stairs/ramps, planning disabled parking areas and arranging existing ones more clearly.

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Comparative analysis among cross background green building rating system: LEED, DGNB, SBAT, and Greenship

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Abstract. In the past decades, Green Building Rating Systems (GBRS) have been developed by many countries and organizations around the world to assess, evaluate and certify the performance of green buildings. Some GBRS have been adopted in different sites around the globe, some GBRS have been developed for a specific country. This study aims to compare Green Building Rating System (GBRS) from different backgrounds, to identify the factors of the background in developing similarities, differences, strengths and weaknesses of each GBRS. Namely from globally used GBRS represented by LEED, national GBRS from developed countries represented by Germany's DGNB, national GBRS from developing countries represented by Indonesia's Greenship, and South Africa's SBAT. To achieve these goals, three steps were taken. The first step is the comparison of the general information of each GBRS, followed by the second step with the comparison of the categories and criteria carried out by each GBRS. To deepen the comparison, LEED, DGNB, Greenship, and SBAT were adopted to evaluate Jakarta International Stadium (JIS) and clearly identify the similarities, differences, strengths, and weaknesses of each GBRS. From the analysis, it was revealed that the different background of the GBRS resulted in different emphasis of the certification categories and criteria. This difference was considered important in the process of selecting the GBRS to be adopted in the building, as reference to a particular GBRS can influence different emphases in the design.

Keywords: Green building rating system, LEED, DGNB, Greenship, SBAT for Stadia, Sustainable development, Green Building

1. Introduction

The building sector is currently the major driver to the environmental impact, where in 2022 building sectors as the biggest CO2 emission contributors up to 37% equals one-third of the global emission (UNEP, 2024). Moreover, the building sector currently consumes 40-50% of resources extracted from global materials (Brady & Kamawura, 2021). These conditions are signalling that building sectors are not at the sustainable level, even their uncontrolled development could become a serious threat. As the responsibility to reduce environmental damage for the future, it is crucial for building sectors to transform the development into more sustainable, in the form of sustainable building (Sidig et al., 2024;Zarghami & Fatourehchi, 2020).

The emergence of a green building rating system (GBRS) in sustainable building sectors is one of the efforts to promote sustainability in construction sector. Green building itself is one of the concepts to encourage the construction sector to use an environmentally friendly approach. But environmental issues are not the only concerning issues. Wellbeing and the cost of green building also becomes critical factors (Zhang, 2014). Thus, the meaning of achieving good performance in GBRS or to be called as 'green' building, where a building must satisfy all environmental, economic, and social parameters of sustainability (Illankoon et al., 2017). According to Munasinghe, the social parameters means building should cover empowerment, inclusion, and governance; economic aspects should cover growth, efficiency, and stability; the environmental aspect covers resilience, natural resources and pollution (Munasinghe, 2004).

Leadership in Energy and Environmental Design (LEED) is one of the pioneers of GBRS, established in 1998 by USGBC (US Green Building Council), eight years different from the first GBRS established by UK in 1990, Building Research Establishment Environmental Assessment Methodology (BREEAM). Although it was release after BREEAM, LEED as voluntary standard was used more globally according to the number of countries that adopting LEED as the rating system (Doan et al., 2017). According to the latest report from USGBC, as 2024, LEED was adopted in 186 countries with total project has reached more than 197.000 (USGBC, 2024).

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From general use to a nationally designed rating system, the form of the GBRS continues to develop. German is one of the countries in Europe that proposing their rating system. The development started in 2001 by publishing Guidelines in Sustainable Building (GSB) in 2001 by the United Ministry of Transport, Construction and Urban Affairs and evolved into DGNB (D*eutsche Gesellschaft für Nachhaltiges Bauen* or German Green Building Council in 2008. The categories in DGNB incorporate the sustainable development dimension: economic, ecology, and social criteria.

Regrettably, the issue of the gap in the international rating system is becoming increasingly clear, especially in the context of its implementation in developing countries. The approach to building construction in developing countries differs significantly from that observed in developed countries. This is because the primary aim of development in developing countries remains the fulfilment of basic needs (Gibberd, 2002). Meanwhile, the international rating system developed based on the context of their origin, ignoring the issues that exist in developing countries (Zarghami & Fatourehchi, 2020).

South Africa is one of the developing countries that has implemented a national rating system in response to the recognition of a gap in the application of the international rating system at the national level. This system, called SBAT (Sustainable Building Assessment Tool), was developed by the CSIR (Council for Scientific and Industrial Research) of South Africa to address the country's ongoing development. The main question guiding the development of this system was how buildings can contribute to sustainable social and economic development, as well as environmental sustainability. According to Gibberd J. (Gibberd, 2002) as one of the contributors to this rating system, SBAT also helps in defining a new objective of sustainable building for developing countries:" sustainable building and construction aims to maximise beneficial social and economic impact while minimising negative environmental impact".

One of SBAT's achievements that is different from some other rating systems was the establishment of SBAT for Stadia as South Africa's response towards the addition of the Green Goal chapter in FIFA's technical guidelines for football stadium development in 2007, as South Africa prepared themself to become the host of 2010 World Cup. It is recorded that previous stadium construction for the Olympics or World Cup never resulting a new rating system focusing on stadium typology, as the stadium for the London Olympics 2012 used BREEAM to assess their construction towards environmentally friendly development while LEED was used in 2006 Torino Winter Olympics. Indicators in SBAT and FIFA World Cup stadia were reviewed, resulting some adjustment in SBAT criteria. The adaptation can be found in the Social criteria, where *Occupant Comfort* and *Day lighting* in regular SBAT was adopted to become *Spectator Comfort* and *Shading* in SBAT for Stadia (Tn & Jt, n.d.). Despite its emergence brought the new development energy to the county, as finding reference regarding the SBAT rating system, limitations in the number of published research were found.

Just like other countries in the world, Indonesia, as a rapidly developing country also started its movement towards sustainable development in the building and construction sector through the establishment of Greenship certification by GBCI (Green Building Council Indonesia). GBCI as a non-government organization (NGO) is committed to educating the public about green building practices and helping the building industry become more sustainable. Alongside developing the rating system, GBCI also aims to transform the building market and spread green building principles to the public (GBCI, n.d.). Although they are not at the government level, the existence of this NGO as a pioneer towards green development is supported by the government through several collaborations in government projects such as the green certification of several ministries' buildings in Jakarta and collaboration with PT. Wijaya Karya (WIKA) a State-Owned Enterprises (BUMN) in developing a certification program called Greenship Net Zero. There are many research studies on the application of Greenship in building design, but only a few research on reviewing Greenship have been found. While research that will trigger evolution in specific certification systems is expected to support the implementation and improvement (Mardhiyana et al., 2023).

With the emergence of GBRS around the world from various backgrounds, comparative studies among various building rating systems have been carried out by several researchers. Published comparative studies have mostly compared GBRS from developed countries and the pioneers of GBRS: LEED and BREEAM (Suzer, 2015;Doan et al., 2017). On the other hand, there are also comparative studies based on inequality related to the background origins of GBRS, but the number is very limited. For example, the comparison between GBRS in developed and developing countries has previously been studied (Zarghami & Fatourehchi, 2020; Doan et al., 2023; Mardhiyana et al., 2023).

Amidst the many comparisons, the selection of the GBRS used still does not seem to match the context. For example, the use of LEED in Vietnam and Indonesia is found to be based on locally developed certifications (Doan et al., 2023;Mardhiyana et al., 2023). In addition, use GBRS in green building projects globally is still dominated by LEED. Although study shows that there are marketing benefits in increasing the property value of LEED buildings certified (Matisoff et al., 2014) and marketing motivates building owners to build greener buildings, but Fenner and Ryce assume that targets for certain levels can lead to 'point hunting' rather than leading to actual sustainable development (Fenner & Ryce, 2008). Meanwhile, it is important for sustainable building to recognize impacts of every design process to natural and cultural resources of the local, regional and global environment (Akadiri et al., 2012). Thus, it is necessary to identify to what extent are evaluated by green building rating tools through credit points, so the selection of GBRS is not only limited to the existing market, but as an encouragement to choose the reference according to the issue at hand. Referring to that, this paper aims to identify the similarities and differences as well as strength and weakness in green building certification system practices across distinct cultural and environmental contexts in three dimensions: international rating system, developed and developing country's national rating system; LEED represent international rating system, DGNB represent developed country's national rating system and Greenship and SBAT represent developing country's national rating system The findings of this paper are also expected to present insights for various stakeholders involved in the green building rating tools development, such as industry professionals and policymakers.

2. Method

2.1 The phases of the research

This paper uses qualitative methods in comparing four GBRS that stand for global scope, national scope in developed country, national scope of developing country and characterized scope rating system. The research carried out by three main steps:

(1) *Comparison of General Attributes*. In this step, performed comparative analysis regarding the general information of each GBRS for new construction mainly rooting from the official websites or publication of the related GBRS.
(2) *Comparison of Criteria*. To analyse similarities and differences as well as the strengths and weaknesses of the analysed GBRS, every indicator was grouped according to common categories. To access data regarding the categories and and indicators of each, the following documents were used:
    - LEED v4.1 Building Design and Construction (LEED, 2024)
    - DGNB System New Construction, Buildings, Criteria Set Version 2023 (DGNB, 2023)
    - Sustainable Building Assessment Tool (SBAT-P) V1(Gibberd, 2003)
    - Greenship for New Building version 1.4 (Green Building Council Indonesia, 2013)
(3) *Comparison through cross background context application*. For deeper analysis, selected GBRT was applied to the building assessment. JIS building becomes a comparative tool in this research, where the assessment of JIS with selected GBRS will be compared. The comparation will be limited on the presence or absence of certain point and analysing the relationship between GBRS with the design result. With this, the analysis of similarities, differences, strengths, and weaknesses of GBRS is expected to be clearer.

2.2 Jakarta International Stadium (JIS) as a case study

Jakarta International Stadium (JIS) is an 82,000-capacity football stadium located in Tanjung Priok, North Jakarta. There is an interesting background of JIS, as the building is standing in a district with the largest number of people under the poverty line compared to other districts in Jakarta. Thus, the construction of JIS is one of the efforts to accelerate urban development in the district. The construction of JIS was primarily carried out by local workers and experts (Azzahra, 2022), and it received the highest level of recognition, Platinum, from the Greenship certification. Stadium typology is considered as the case study in this comparative study since stadium construction is counted as a mega-structure that involves major investment, but in contrast shows in many cases become a threat once the event is over. The construction of the stadium as a mega-structure is mentioned to comprise a large amount of carbon footprint and often becomes a financial burden both for the owners and the local community around the stadium after the event due to the lack of utilization and maintenance (Francis et al., 2023;Azzali, 2019). These addressing that sustainable stadium construction is highly directed to all aspects of sustainability, as viewed from the standpoint of the entire rating system.

The study about the comparison between Greenship and LEED within the performance of JIS was previously done by Hanif (Hanif, 2022), one of stakeholders from JIS construction, PT. Jakarta Propertindo. The data obtained in the study regarding JIS and its sustainable tool and performance in achieving Platinum Greenship considered to be valid data that can be used in this paper. Moreover, the result of the comparative analysis towards Greenship and LEED in the study was considered to be useful in extending wider comparative study.

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Greenship certification is carried out in two phases, namely design recognition (DR), where the assessment is carried out to see how the building complies with the green building principle, and the final assessment (FA) phase through on-site evaluation to see the overall performance of the building. The ratio between DR and FA is 77%

and 23%, which means that differences may occur after FA, but are less significant to the total score. Table 1 shows the performance of JIS in each assessment criterion during DR and FA. On the FA, all of the criteria received a score above 50%, where ASD received 59%, energy performances received 85%, water performances received 81%, material received 71%, indoor comfort performance received 70%, and environmental management performance received 77%. The final score obtained has a slight difference with the DR stage, where DR stage of JIS show the results of 81.8% (Hanif, 2022). The difference can occur because there are several indicators in FA that have not reached the maximum in the on-site evaluation.

Fig. 1. Jakarta International Stadium (StadiumDB, n.d.)

Table 1. Greenship Assessment of Jakarta International Stadium

Greenship Assessment Criteria	**Max. Score (DR)**	**JIS's Score (DR)**		**Max. Score (FA)**	**JIS' Score (FA)**	
Appropriate Site Development (ASD)	17	12	70.6%	17	10	59%
Energy Efficiency and Conservation (EEC)	26	24	92.3%	26	22	85%
Water Conservation (WAC)	21	18	85.7%	21	17	81%
Material Resource and Cycle (MRC)	2	2	100.0%	14	10	71%
Indoor Health and Comfort (IHC)	5	4	80.0%	10	7	70%
Building & Environmental Management (BEM)	6	3	50.0%	13	10	77%
Total achieved point	**77**	**63**	**81.8%**	**101**	**76**	**75%**

3. Result and Disussion

3.1 General characterization of GBRT: Overview of LEED, DGNB, SBAT and Greenship

Table 2 presents general information on four major Green Building Rating Systems (GBRS) likely to influence indicator formulation and weighting. LEED, one of the pioneers, is not limited to national use; its global adoption spans over half the countries worldwide. DGNB, though newer than SBAT for Stadia, is implemented in over 30 countries. According to Kouka et al. DGNB aligns most closely with the European Green Deal among European GBRS, suggesting its adaptability beyond national boundaries (Kouka et al., 2024).

SBAT emerged earlier than Greenship (GS) and several GBRS in developed countries (Zarghami & Fatourehchi, 2020a), yet records of its application and updates are scarce. GS, Indonesia's national GBRS, is the most recently established among the four, with a lower number of applications than DGNB. Green building adoption in emerging countries lags behind developed nations due to perceived higher risks in sustainable construction (Nguyen et al., 2023). Nonetheless, GS saw a notable increase in 2024, with 40 new certified buildings (Mardhiyana et al., 2023).

DGNB and SBAT were initiated by government institutions, while LEED and GS were developed by non-governmental Green Building Councils. Despite this, both LEED and GS are officially recognized. LEED is accepted for building tax incentives in the U.S., and GS is similarly recognized by regional governments in Indonesia, with government support seen in public project certifications (GBCI, n.d.).

However, GS and SBAT have experienced significantly slower updates than LEED and DGNB. GS has not been updated for over a decade, and SBAT Regular has remained unchanged for more than 20 years. SBAT for Stadia is its most recent update, prompted by the World Cup. As Fenner & Ryce (2008) note, continual evolution of GBRS is vital to sustain momentum in sustainable development and reach new markets (Fenner & Ryce, 2008).

Table 2 also compares the assessment criteria categories. LEED and GS emphasize key design and construction factors affecting sustainability outcomes. In contrast, DGNB and SBAT are structured around the three pillars of sustainability—economic, social, and environmental. DGNB further includes Technical, Process, and Site Quality categories, which complement its core evaluation areas. This topic is explored in detail in the "Comparison of Categories" section.

Table 2. Comparison of General characterization of LEED, DGNB, SBAT and Greenship (table edited).

	LEED	**DGNB**	**SBAT**	**GS**
Year	1998	2007	2001	2010
Origin	USA	Germany	South Africa	Indonesia
Organization	USGBC	DGNB	CSIR	GBCI
Adaptation in other country	186	30	1	1
First version	1998	2007	2001	2010
Latest version	2019 (V4.1)	2023	2003	2013 (V1.2)
Rating level	Certified >= 40 Silver >= 50 Gold >= 60 Platinum >= 80	Bronze >=35%* Silver >=50% Gold >=65% Platinum >=80%		Bronze >=35%* Silver >=46% Gold >=57% Platinum >=73%
Number of certified buildings	>190.000	>10.000	-	146
Average project (yearly)	7.307	588	-	40

3.2 Comparison of categories

The GBRS categories were compared by grouping into several categories by the similarities. Category comparison is made by identifying and aligning the indicators and grouping based on the common topics. It should by highlighted that comparison is not limited only to the same category name, but to the context of the indicators. This was done since there are different approaches of GBRS's category (LEED and GS, DGNB and SBAT), resulting different title but covering the same context. After that, we also analysing what topics are emphasized in each GBRS by marking indicator with the high score. The result of the comparison is shown in

Fig. *2*.

The Common Categories; As a final, the indicator of LEED, DGNB, SBAT, and GS was grouped into eleven topics: Site, Energy, Water, Material and Resources (MR), Indoor Environment Quality (IEQ), Waste, Management, Innovation, Social, Economy, and Technical Quality. In the grouping process, even though according to literature occupants' health and comfort is included as social aspects, but it is found that several GBRS only assess social aspect only up to health and comfort. Since this paper aims to have deeper analysis in GBRSs' differences and strengths, social aspect that also cover empowerment, inclusion and governance was excluded on the separated group. All GBRS share four common topics categories in Site, Energy, Water, MR and IEQ. According to Nevado-Pena et al., three out of four common topics such as site (land use), Energy, Water, and MR referring to environmental dimensions of sustainability (Nevado-Peña et al., 2015). Meanwhile only IEQ refers to social aspects of sustainability (Illankoon et al., 2017). From that, even though with the same goal towards sustainability development, it shows that each GBRS have the common concern in environmental aspect but different extension in the social and economic aspects.

Prominent Strength of LEED; Among six categories in LEED, a high score category owned by Energy, Location and Transportation included in Site, and Indoor Environmental Quality. This is in line with LEED's aims, as according to the official website of LEED (USGBC, n.d.), 60% of LEED indicator is related to the environment (climate change, water source, and biodiversity), 20% to human health, and the rest is green economy and community. Zimmermann et al. (Zimmermann et al., 2019) address this case by describing LEED and 'Green Building' certification rather than 'Sustainable Building' certification, even though LEED has correlated their indicator with the UN's Sustainable Development Goals. Originating from the developed country become a factor in the environmental aspect's suppression in LEED. Developed countries such as US, can be identified as a country that has reached the economic stability by the GDP value as well as the assurance in the social aspect. These results formulated GBRS has addressed the environmental aspect as a priority instead of social and economic aspect, as it is pointed out by Zarghami and Fatourehci (Zarghami & Fatourehchi, 2020). With the high existences of LEED as the global GBRS, it can be taken to note that LEED is suitable for the project that focus to minimize the environmental impact rather than to reach out as sustainable development approach.

Greenship's Notable Strength; Unlike international GBRS, national-based GBRS shows different criteria formulations. Sharing the same parent organization as LEED, GS highlights similar categories but prioritizes Water over Indoor Environment Quality and even Site development. This emphasis stems from Indonesia's serious water issues, despite its high rainfall and coastal geography. Problems like water supply-demand imbalance, erosion from palm oil plantations, poor sanitation, mining contamination, groundwater over-extraction, and increased flooding (USAID, 2021) led to GS focusing on Water Conservation (WAC) as a prerequisite, stressing water metering, usage calculation, and Water Use Reduction. Even in the Appropriate Site Development (ASD) category, GS emphasizes Storm Water Management to encourage rainwater reuse instead of burdening city drainage systems.

Moreover, while GS indicators appear similar to LEED, there are notable adjustments to prerequisites and the addition of new indicators, influenced by technological differences and local culture. For instance, "Environmental Tobacco Smoke Control" is mandatory in LEED but a high-value (non-mandatory) indicator in GS, reflecting Indonesia's strong smoking culture (Nua, 2024; Salsabila et al., 2022). Similarly, "Renewable Energy" is treated as a bonus in GS due to challenges like expensive solar power investments in developing countries (Pristiandaru, 2023) and Indonesia's reliance on imported solar panels due to limited local production (Thomas, 2019).

Stand-Out Aspects in DGNB; Despite DGNB originated from a developed country, they emphasize all the pillars as equally by providing equal weight to each pillar namely Environmental Quality which includes indicator in Site, Energy, and Water, Socio-Cultural and Functional Quality which includes Indoor Environment Quality, and Economic Quality. The perspective used by DGNB creates this rating system is not just a 'Green Building' rating system, but a 'Sustainable Building' rating system. Initiated from Guidelines for Sustainable Building (GSB) by The Ministry of Transport, Construction and Urban Affairs Germany, lead the GBRS developed by Germany to stick with the sustainable principle. According to

Fig. *2*, the indicators in DGNB are only missing in two categories: Waste and Innovation. However, this does not mean that they are not considered. The discussion of this finding takes place later in Waste and Innovation categories discussion.

DGNB also shows another unique side through the category 'Technical Qualities' which is only found in DGNB. This category specifically encourages building envelope quality, in-building technology, reuse of site potential, and mobility infrastructure. This category is mentioned to "strongly influence the other sustainability qualities in the early planning phase" and "determines the degree to which the planned quality is implemented during execution' (Federal Ministry for the Environment, 2016). Technical categories also can cover the reliability, durability, flexibility, and adaptability of the system (Illankoon et al., 2017).

SBAT Noticeable Strength; SBAT has general points for assessing green buildings with the main categories using triple bottom line of sustainability. The formulation of SBAT indicators projects the conditions of its home country in the consideration of indicators. By using a sustainable approach in the formulation of indicators such as that used by the DGNB, it provides an explanation that may not be available in other GBRS. In the Location category, which reflects the issue of food security in South Africa, "Food garden" is a separate indicator.

The Different Extension towards Economic and Social Sustainability; In the Economy category, promoting local contractors, materials, components, and furniture is explicitly mentioned, along with considerations like Efficiency, On-going Cost, and Capital Cost—elements absent in GS and LEED. These align with Munasinghe's (2004) elements of economic sustainability: growth, efficiency, and stability, showing that SBAT and DGNB address both environmental and economic "Green" performance.

For the social aspect, LEED and GS do not assess design inclusivity, unlike DGNB and SBAT for Stadia. DGNB emphasizes "Barrier-free design" to promote inclusivity, while SBAT adds categories like "Social-Participation Control" and "Social-Education, Health, and Safety," reflecting South Africa's high social inequality (World Bank, 2022). This shows the relevance of social considerations, especially in large community buildings like stadiums. Education-related health issues, like HIV/AIDS control, are only found in SBAT for Stadia, highlighting the link between local health conditions and building certification—an approach other GBRS could adopt.

The lack of social and economic assessments in LEED and GS undermines a full sustainability approach, as sustainable buildings should balance the triple bottom line (Illankoon et al., 2017). Studies also show LEED's weakness in this area (Doan et al., 2017; Zarghami & Fatourehchi, 2020; Ferreira et al., 2023). Meanwhile, government-developed GBRS like DGNB and SBAT address sustainability more comprehensively (Mardhiyana et al., 2023), suggesting that LEED and GS could improve to better suit developing countries' needs.

The Differences in Waste Category Assessment; It is noticeably found that in the Waste category, only SBAT gives separate space for waste assessment. GS assess waste from the BEM category, the 'Basic Waste Management' indicator as it promotes domestic waste management for building operations becomes a prerequisite. Both show differences with other GBRS from developed countries. LEED assess waste in MR category, with the aim to managing waste related to the construction activity. Meanwhile, DGNB did not put 'waste' in any title of the indicator. Instead, DGNB discussed it in the 'PRO2.1 – Construction site/construction process' instead. Where in the mentioned indicator, waste is discussed together with noise, dust, and negative impacts to soil and groundwater during the construction process.

It is interesting since international and developed country's GBRS such as LEED and DGNB assess waste in the indicator to the construction process only, while GBRS from developing countries such as SBAT for Stadia and Greenship assess waste up to the operation phases. Even in GS, indicators for waste during construction are not mandatory, and the priority is taken by waste management during the sage of the building. Positively, LEED, DGNB, SBAT for Stadia and GS promotes adaptive reuse of old structure as one of the ways to fulfil the indicator, which is one of the efforts to run the circular economy (Potting et al., 2016).

The differences in Waste assessment can be triggered by differences in waste management conditions in the country of origin. It is reported that South Africa has been working in the waste and recycling landscape by funding and technical expertise, but the progress has remained slow in the non-packaging waste stream including in construction and demolition waste and organic waste (Godfrey & Oelofse, 2017). In Indonesia's case, it is reported that waste management is still not optimal and sustainable condition (Kusumaningrum et al., n.d.). Different from the condition in the US, where the US already implemented the Environmental Protection Agency (EPA) and 3R (reduce, reuse, recycle) and implemented the recycling program with a goal of utilizing solid waste up to 50% (Kerenhapukh et al., 2021). A Similar condition within Germany, where a waste management policy has been adopted for more than 20 years successfully increasing people's awareness to separate waste and implement disposal technology, leading to 14% of raw materials used by the German industry are from recovered waste (Nelles et al., 2016). The contrasting conditions between the countries of origin of the GBRS may give some insight into the indicators listed. Where the indicators are a directive towards the improvement of the conditions that are still lacking in the country.

Spaces for Innovation Activity in GBRS; Regarding the opportunity to innovate in design, despite the condition of the country, LEED and SBAT for Stadia encourage innovation in assessing green buildings as we can see in

Fig. *2*, Innovation technology. But while DGNB does not have a specific category for innovation, it integrates innovation as a bonus option in the overall certification, mentioned as the "Innovation Area" segment in the guidelines (Fig. 3). As for GS, the term 'innovation' is not mentioned directly in the handbook. What is included is an encouragement to 'use innovative technologies' to achieve targets on water efficiency only. The innovation activity promoted by GBRS in line with a statement by OECD (Organisation for Economic Co-operation and Development) where innovation in the form of creation of new products, processes and technologies, as well as the diffusion and application in green development is helpful to achieve green growth (OECD, 2011). Therefore, the addition of separated indicators for innovation is recommended for GS to catch up with the current condition.

SITE

LEED	Integrative process (1)	Integrative Project Planning and Design* Integrative Process
	Sustainable sites (10)	Construction Activity Pollution Prevention * Site Assessment Site Development - Protect or Restore Habitat Open Space Rainwater Management** Heat Island Reduction Light Pollution Reduction
	Location and Transportation (16)	LEED for Neighborhood Development Location* Sensitive Land Protection High Priority Site Surrounding Density and Diverse Uses** Access to Quality Transit** Bicycle Facilities Reduced Parking Footprint Green Vehicles
DGNB	Site quality (5,1)	SITE1.1 – Local environment SITE1.3 – Transport access SITE1.4 – Access to amenities
	Environmental quality (25)	ENV2.3 – Land use ENV2.4 – Biodiversity at the site
SBAT	Environmental - Site	EN 4.1 Brownfield site EN 4.2 Neighbouring buildings EN 4.3 Vegetation EN 4.4 Food gardens** EN 4.5 Landscape inputs
	Social - Inclusive environment	SO 2.1 Public Transport
	Social - Access to facilities	SO 3.1 Children SO 3.2 Banking** SO 3.3 Retail** SO 3.4 Communication SO 3.5 Exercise
GS	Appropriate Site Development (ASD) (17)	Basic green area* Site selection Community accessibility Public Transportation Bicycle facility Site landscaping** Micro climate** Stormwater Management**

SOCIAL

LEED	-	
DGNB	Socio-cultural and functional quality (25,2)	SOC2.1 – Barrier-free design
SBAT	Social - Inclusive environment	SO 2.3 Space** SO 2.4 Toilets SO 2.5 Fittings & Furniture
	Social - Participation control (1,1)	SO 4.1 Environmental control SO 4.2 Lighting control** SO 4.3 Social spaces SO 4.4 Sharing facilties** SO 4.5 User group
	Social - Education,	SO 5.1 Education SO 5.2 Safety** SO 5.3 Awareness** SO 5.5 Accidents
GS	-	

ECONOMY

LEED	-	
DGNB	Economic quality (25)	ECO1.1 – Life cycle cost** ECO2.4 – Value stability** ECO2.6 – Climate resilience ECO2.7 – Documentation
SBAT	Economy - Local economy	EC 1.1 Local contractors EC 1.2 Local materials EC 1.3 Local components EC 1.4 Local furniture/fittings EC 1.5 Maintenance
	Economy - Efficiency	EC 2.1 Capacity** EC 2.2 Occupancy EC 2.3 Space per occupant** EC 2.4 Communication
	Economy - Adaptability	EC 3.1 Vertical heights EC 3.2 External space** EC 3.3 Internal partition** EC 3.5 Furniture
	Economy - On going cost	EC 4.1 Induction EC4.2 Consumption & waste** EC 4.2 Metering** EC4.3 Maintenance & Cleaning**
	Economy - Capital cost	EC 5.1 Local need EC5.2 Procurement** EC 5.3 Building costs**
GS	-	

WASTE

LEED	Materials and Resources (13)	Storage and Collection of Recyclables* Construction and Demolition Waste Management Planning* Construction and Demolition Waste Management
DGNB		
SBAT	Environmental - Waste	EN 3.1 Toxic waste EN 3.2 Organic waste EN 3.3 Inorganic waste** EN 3.4 Sewage** EN 3.5 Construction waste
GS	Building Environment Management (BEM) (13)	Basic Waste Management* Pollution of Construction Activity Advanced Waste Management

MANAGEMENT

LEED	-	
DGNB	Process quality (10,2)	PRO1.1 – Quality of project preparation PRO1.4 – Ensuring sustainability aspects in tendering and contracting PRO1.6 – Procedure for urban and design planning PRO2.1 – Construction site/construction process PRO2.3 – Systematic commissioning PRO2.5 – Preparation for sustainable use
SBAT	-	
GS	Building Environment Management (BEM) (13)	GP as a Member of Project Team Proper Commissioning* Green Building Submission Data Fit Out Agreement Occupant Survey

INNOVATION

LEED	Innovation (6)	Innovation* LEED Accredited Professional
	Regional Priority (4)	Regional Priority: Specific Credit Regional Priority: Specific Credit Regional Priority: Specific Credit Regional Priority: Specific Credit
DGNB	-	
SBAT	Economy - Capital cost (2,1)	EC5.4 Technology
GS	-	

WATER

LEED	Water Efficiency (11)	Outdoor Water Use Reduction* Indoor Water Use Reduction* Building-Level Water Metering* Outdoor Water Use Reduction Indoor Water Use Reduction** Cooling Tower Water Use Water Metering
DGNB	Environmental quality (25)	ENV2.2 – Potable water demand and wastewater volume
SBAT	Environment - Water	EN 1.1 Rainwater EN 1.2 Water use EN 1.3 Runoff** EN 1.4 Greywater** EN 1.5 Planting
GS	Water Conservation (WAC) (21)	Water Metering* Water Calculation* Water Use Reduction** Water Fixtures Water Recycling Alternative Water Resources Rainwater Harvesting Water Efficiency Landscaping

INDOOR QUALITY

LEED	Indoor Environmental Quality (16)	Minimum Indoor Air Quality Performance* Environmental Tobacco Smoke Control* Enhanced Indoor Air Quality Strategies Low-Emitting Materials** Construction Indoor Air Quality Management Plan Indoor Air Quality Assessment Thermal Comfort Interior Lighting Daylight Quality Views Acoustic Performance
DGNB	Socio-cultural and functional quality (25,2)	SOC1.1 – Thermal comfort SOC1.2 – Indoor air quality SOC1.3 – Sound insulation and acoustic comfort SOC1.4 – Visual comfort SOC1.6 – Quality of indoor and outdoor spaces
SBAT	Social - Spectator comfort	SO 1.1 Shading** SO 1.2 Ventilation SO 1.3 Noise SO 1.5 Thermal comfort SO 1.5 Views
	Social - Inclusive environment	SO 2.2 Information**
	Social - Education, Health, and Safety	SO 5.4 Materials
GS	Indoor Health and Comfort (IHC) (10)	Outdoor Air Introduction* CO2 Monitoring Environmental Tobacco Smoke Control** Chemical Pollutant** Outside View Visual Comfort Thermal Comfort Acoustic level

ENERGY

LEED	Energy and Atmosphere (33)	Fundamental Commissioning and Verification* Minimum Energy Performance* Building-Level Energy Metering* Fundamental Refrigerant Management* Enhanced Commissioning Optimize Energy Performance** Advanced Energy Metering Demand Response Renewable Energy Production Enhanced Refrigerant Management Green Power and Carbon Offsets
DGNB	Environmental quality (25)	ENV1.1 – Climate action and energy**
SBAT	Environmental - Energy	EN 2.1 Location EN 2.2 Ventilation** EN 2.3 Heating & Cooling** EN 2.4 Appliances & fittings EN 2.5 Renewable energy
GS	Energy Efficiency and Conservation (EEC) (26)	Electrical sub metering* OTTV calculation* Energy efficiency measures** Natural lighting* Ventilation Climate change impact On site renewable energy***

MATERIALS AND RESOURCES

LEED	Materials and Resources (13)	Building Life-Cycle Impact Reduction* Building Product Disclosure and Optimization - Environmental Product Declarations** Building Product Disclosure and Optimization - Sourcing of Raw Materials Building Product Disclosure and Optimization - Material Ingredients
DGNB	Environmental quality (25)	ENV1.2 – Local environmental impact ENV1.3 – Responsible resource extraction
SBAT	Environmental - Materials and Components	EN 5.1 Embodied energy EN 5.2 Material sources** EN 5.3 Ozone depletion** EN 5.4 Recyled / reuse EN 5.5 Construction process
	Economy - Capital cost	EC 5.5 Existing
	Economy - Efficiency	EC 2.5 Material & Components
	Economy - Adaptability	EC 3.4 Modular planning
GS	Material Resources and Cycle (MRC)	Fundamental Refrigerant* Building and Material Reuse Environmentally Friendly Material** Non ODS Usage Certified Wood Prefab Material** Regional Material

TECHNICAL QUALITY

LEED	-	
DGNB	Technical quality (9,9)	TEC1.3 – Quality of the building envelope TEC1.4 – Use and integration of building technology TEC1.6 – Circular construction** TEC3.1 – Mobility infrastructure
SBAT	-	
GS	-	

[shaded box]: Highlighted categories (have high point presentation)

** : Prerequisite indicators **: Highlighted indicators (have high point presentation) ***: Bonus*

Fig. 2. LEED, DGNB, SBAT, and Greenship (GS) indicators comparation

To1–5	**INNOVATION AREA – Circular digital building twin** Digital building twin completely designed for circularity (as-built quality, with open interface and updatable database in the background) is integrated into the project in the early design phase and contains all circular information about the entire life cycle at the end of the documentation.	100
for 4	**INNOVATION AREA** Innovative, individual solutions that create a pleasant, suitable qualities of space in the access and circulation areas.	as 4.1

Fig. 3. Innovation Area in DGNB Guidelines (DGNB, 2023)

3.3 Comparison through cross background context application

This section compares GBRS—GS, LEED, DGNB, and SBAT—based on JIS performance. In case of SBAT, the analysis adjusted to the SBAT for Stadia version, tailored for stadium projects. Notably, the 'Occupants Comfort' indicator becomes 'Spectators Comfort', where daylighting is replaced with shading; other indicators remain unchanged.

Based on the LEED assessment, JIS falls short in MR, Energy, and IHC categories. Similarly, DGNB and SBAT for Stadia highlight gaps in economic and social aspects, particularly in inclusive design. However, JIS satisfies the Water and Site categories across the systems.The MR shortfall in JIS is linked to lifecycle assessment, which GS does not explicitly include. DGNB does incorporate this, particularly regarding demolition waste—an aspect absent in GS and SBAT. Despite national waste management differences, post-occupancy scenarios, as noted by Fregonara et al. (2018), are critical for long-term sustainability, especially for large-scale facilities (Fregonara et al., 2018).

Stadium-specific assessments in GS and SBAT for Stadia shows differ in focus. JIS meets GS's 'Thermal Comfort' criteria through energy-saving envelope design, aligned with LEED and DGNB. Conversely, SBAT for Stadia prioritizes passive cooling via roof shading. The unique 'Spectators Comfort' indicator in SBAT for Stadia, replacing 'Daylighting', reflects the needs of semi-open stadiums, where excess sunlight can impact occupant comfort and health. Research supports roof shading as more effective than natural ventilation (Guo & Sun, 2024; Conradie, 2018), highlighting SBAT's critical evaluation of social sustainability aspects.

Further, JIS shows deficiencies in meeting the economic and social indicators emphasized by DGNB and SBAT. These systems assess not only environmental but also community and long-term economic impacts. In JIS's context—built in a dense urban area requiring relocation—DGNB's 'Quality of Indoor and Outdoor Spaces' and SBAT's 'Participation and Control' indicators stress community integration. Similarly, economic indicators examine building longevity, cost-effectiveness, and societal value—essential for projects with high public investment and social implications.

Nonetheless, GS performs well in Water and Site Development, consistent with its high standards in these areas. Meanwhile, the unique SBAT category of 'Spectators Comfort'—focused on lighting—has limited impact on overall assessment.

Ultimately, JIS meets over half the criteria in LEED, DGNB, and SBAT. However, its shortcomings reflect the differing priorities among GBRS, shaped by their regional origins. While all aim for sustainability, each system applies distinct strategies based on local contexts.

4. Conclusions

Green Building Rating Systems (GBRS) have been developed by many countries and organizations around the world to assess, evaluate and certify the performance of green buildings. Some GBRS have been adopted in different sites around the globe, some GBRS have been developed for a specific country, and some of them are specially made for special occasions. This study address to compare GBRS from different backgrounds, to identify the similarities, differences, strengths and weaknesses of each GBRS.

As the result of the comparison, it shows that all GBRSs are similar in their focus on environmental aspects, addressing categories such as site, energy, water, MR, and social aspects through IEQ. However, differences in their backgrounds lead to variations in the indicators they evaluate, presenting both strengths and opportunities for improvement. From this research, it can be suggested for stakeholders in the construction field to choose locally developed GBRS as a green building reference to access regionally specific sustainability issues. In addition, it is expected that the wide use of regional GBRS can lead to the development of GBRS periodically, especially in improvement areas found at several points. That way, the goal of future sustainability can be achieved.

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A review on artificial intelligence extensions integrated into architectural drawing programs and their applications

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Abstract. Artificial intelligence is creating a significant transformation in the field of architecture by offering advantages such as accelerating design processes, reducing the margin of error and producing creative solutions. Artificial intelligence technologies integrated into architectural software not only facilitate design processes, but also provide more sustainable, economical and innovative solutions. In order to examine the role of AI in architectural design, this study provides a comprehensive overview of AI extensions and design-based AI applications integrated into architectural drawing programs. The aim of the study is to analyze in detail the functions and usage areas of artificial intelligence in software such as AutoCAD, Revit, Rhino+Grasshopper, Fusion 360, Sefaira, Lumion, Enscape, Twinmotion and SketchUp. In addition, the transformative effects of AI in areas such as parametric design, energy efficiency analysis and sustainability-oriented modeling are highlighted. As a methodology, a literature review and technical review of existing software features were conducted. In this process, the effects of AI on generative design, data analytics, energy simulations and visual presentation processes were evaluated. It has been observed that AI-supported extensions make the design processes more efficient and effective, while at the same time improving the design quality. The results of the research show that artificial intelligence is faster in architectural design processes, encourages innovation and offers designers more flexible, functional and aesthetic solutions. The study predicts that the integration of artificial intelligence into architectural software will have a wider application area in the future and will make significant contributions to the discipline of architecture.

Keywords: Artificial Intelligence (AI); Architectural Design; Desing Program, Architecture

1. Introduction

With the influence of digitalization, architectural drawing and modeling programs have undergone a profound transformation over the past forty years. Initially limited to producing two dimensional drawings, computer-aided design (CAD) programs have evolved into multifunctional tools encompassing three dimensional modeling, building information modeling (BIM), parametric design, energy simulation, and visualization (Eastman et al., 2011). This evolution has reshaped both architectural education and professional production processes.

Contemporary architectural practice now encompasses not only aesthetic and functional design but also sustainable, economical, and technologically innovative solutions marking a shift toward a multidimensional design process (Yang et al., 2025). One of the primary driving forces behind this transformation is the integration of artificial intelligence (AI) technologies into design workflows. The use of AI in architecture has become increasingly visible alongside the digitalization of design processes, enabling designers to make faster, data driven, and optimized decisions. As architectural practice has shifted from traditional drawing methods to digital modeling, drawing software has likewise transformed from being merely two-dimensional drafting tools to becoming integrated platforms equipped with three-dimensional modeling, analytical, and simulation capabilities. These platforms (Revit, AutoCAD, Rhino+Grasshopper) now not only support drawing production but also offer intelligent systems that guide user decisions, propose alternative solutions and analyze various scenarios simultaneously (Li et al., 2024). In this context, AI-supported extensions and plugins have significantly transformed conventional design practices.

However, despite this rapid technological advancement, several questions remain inadequately addressed: How is AI integrated into architectural software? What specific functions do these AI extensions perform? What types of contributions do they make to the design decision-making process? These unresolved issues highlight a substantial knowledge gap in both academic literature and professional practice (Jang & Lee, 2025). A systematic

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assessment of the nature, functions, and advantages of AI tools integrated into architectural software is therefore necessary.

With the development of digital design tools, AI powered extensions now go beyond merely facilitating production processes they enable complex functions such as generating alternative solutions, conducting performance analyses, and integrating sustainability criteria. Yet, the existing literature on how these technologies are integrated into various software platforms, what contributions they offer, and in which contexts they are most effectively used remains limited. Most studies focus on individual software programs or tools and fail to provide a comprehensive evaluation.

The primary aim of this study is to systematically examine AI extensions integrated into commonly used architectural drawing and modeling software and to explore their multifaceted contributions to the architectural design process. Through an evaluation of software platforms such as AutoCAD, Revit, Rhino+Grasshopper, Fusion 360, Sefaira, Lumion, Enscape, Twinmotion, and SketchUp, the study details the scope of AI-supported functions in relation to design workflows, analysis, visualization, and performance optimization. The research focuses on the following central questions:

- What functions do AI extensions perform in architectural drawing programs?
- How do these technologies contribute to subdomains such as sustainability, energy efficiency, and visualization?

Within this framework, the study seeks to contribute to the existing literature while also offering a technical and conceptual perspective on the future of architectural design. It emphasizes that the integration of AI into architectural software represents not only a technological innovation but also a paradigm shift that is transforming the culture of design. The analysis will evaluate the technical functions, areas of application, and representation in the literature of these software programs and extensions, and will discuss their impact on architectural practice. Without relying on surveys or applied data, this study, conducted through a literature based approach, aims to present a comprehensive overview of AI integration in architectural software and to lay the groundwork for future critical inquiry.

2. Theoretical Background of Artificial Intelligence Integration in Architectural Drawing Programs

Artificial intelligence (AI), while generally referring to the development of computer systems that mimic human intelligence, in the context of architecture, entails a redefinition not only of computational capacity but also of the creative process itself. In architecture, AI transcends traditional design processes and functions as a tool that supports multi-layered workflows such as parametric design, generative algorithms, data analytics, and optimization. This transformation directly influences the architectural thought system at both cognitive and productive levels

2.1. The Definition and Role of Artificial Intelligence in Architecture

Architecture has historically evolved as a design practice grounded in intuition, experience, and cultural values. Today, however, the computational power offered by AI enables the reconstruction of this practice in digital environments through data driven approaches. AI, particularly through areas such as machine learning (ML), deep learning (DL), generative design, and algorithmic thinking, is becoming one of the guiding components of the design process (Oxman, 2017). In this context, the architect is no longer merely a designer but a strategist who co-directs the design process alongside algorithms.

2.2. Conceptual Foundations of AI Integration

Generative design allows AI algorithms to automatically produce various design alternatives based on predefined input parameters. This approach is exemplified in software such as Autodesk Revit, where the "Generative Design" module offers designers a range of optimal solutions aligned with specific goals such as energy efficiency, spatial utilization, or aesthetic coherence. This significantly facilitates decision-making, especially during early design stages (Turrin et al., 2011). In Rhino + Grasshopper environments, AI based plugins such as Wallacei and Opossum utilize evolutionary algorithms to test design variations and recommend optimized solutions. These tools not only accelerate the design process but also exceed human capacity in solving complex, multi variable problems.

2.3. Generative Design Approach and Computational Thinking

The integration of AI into architectural software is not only a technical instrument but also a new mode of thought. Accordingly, the design process is increasingly reduced to a problem solving algorithm, and the designer becomes a "cognitive operator" who manages this algorithm. Machines should be considered not merely as tools, but as "collaborative designers"a vision that has become increasingly tangible with today's AI integrations (Vartiainen, 2021).

Furthermore, generative AI models such as Midjourney and DALL·E can directly influence the formal articulation of design, allowing AI to operate not only in the background as a support tool, but also in the foreground as a "designer" capable of form generation. This challenges the traditional human-centered paradigm of architectural theory and prompts a critical reassessment of authorship in design.

3. Examination of Architectural Drawing Software and Integrated AI Extensions

As architectural design processes undergo transformation through digital technologies, they are evolving beyond traditional CAD (Computer Aided Design) tools into systems that integrate data driven, computational, and adaptive structures. In this evolutionary process, artificial intelligence (AI) has emerged not merely as an auxiliary module within architectural software but as a generative system actively participating in decision-making. Designers now work alongside systems that not only generate geometric forms but also simulate performance, conduct optimization, and propose alternative solutions. In this context, the integration of AI into architectural software has fundamentally altered the nature and operation of the design process.

With the rapid advancement of technology, architectural design processes have shifted from form based visual production toward a structure grounded in data driven analysis, automation, environmental simulation, and performance based decision support systems. Within this transformation, AI particularly through various modules and extensions integrated into drawing and modeling software significantly enhances both the efficiency and quality of the design process. These platforms, which have replaced traditional drafting tools, now function as intelligent systems capable of analyzing architectural problems in multidimensional ways and proposing optimal alternatives.

This section examines nine major software programs commonly used in architectural design: AutoCAD, Revit, Rhino+Grasshopper, Fusion 360, Sefaira, Lumion, Enscape, Twinmotion, and SketchUp. Each program is evaluated under separate subheadings in terms of its mode of AI integration, the algorithms employed, functional advantages offered to the user, and its representation within the academic literature.

3.1 AutoCAD ve Autodesk Assistant

AutoCAD is a widely used 2D and 3D drafting software in the fields of architecture, engineering, and construction. Its artificial intelligence integration is primarily realized through systems such as Autodesk Assistant and MyInsights. These systems analyze user behavior to predict the most frequently used commands, detect drawing errors in advance, and accelerate the drafting process by offering suggestions (Maheshwari & Agrawal, 2024). The "Smart Blocks" feature, integrated into the latest versions of AutoCAD, enables the automatic placement and adjustment of objects by recognizing them.

3.2 Revit ve Generative Design

Autodesk Revit is a building information modeling (BIM) oriented software that is particularly used in planning building functions through AI supported generative design tools. With its Generative Design module, Revit generates a wide range of design alternatives based on user defined criteria (such as circulation, lighting, and space efficiency) and performs performance analyses to suggest optimal solutions (Turrin et al., 2011). In this process, AI participates directly in decision-making both visually and numerically.

3.3 Rhino + Grasshopper: Wallacei, Opossum, Dodo

Rhino is a powerful CAD software that enables free form modeling. Through its Grasshopper plugin, it facilitates a transition into parametric design processes. AI supported extensions such as Wallacei, Opossum, and Dodo generate optimized designs using evolutionary algorithms and machine learning. These tools are particularly effective in solving complex, multi variable design problems in areas such as form exploration, structural stability, and light analysis (Ekici, 2022). The Rhino/Grasshopper combination serves as a robust generative design platform in both architectural and industrial design domains.

3.4 Fusion 360: AI-Supported Design Focused on Fabrication

Fusion 360 is an integrated CAD/CAM/CAE software developed by Autodesk. While it is widely used in mechanical engineering and product design, it is also preferred for the detailed fabrication of architectural components. The Generative Design module within Fusion 360 produces solutions that offer the most durable form using minimal material, in accordance with structural requirements. In this context, AI undertakes the role of simulation supported generative optimization (Shrestha et al. 2021).

3.5 Sefaira: Energy Performance and AI-Supported Simulation

Sefaira is a software primarily used for building energy modeling, natural lighting analysis, and environmental assessments. Compatible with both SketchUp and Revit, it employs artificial intelligence to analyze factors such as energy consumption, daylight efficiency, and thermal comfort in real time. Sefaira's AI based simulation engine provides performance feedback during the early stages of the design process, facilitating the development of sustainable solutions (Komatina et al., 2024).

3.6 Lumion: Real Time AI-Supported Visualization
Lumion is a powerful rendering software used for visualizing architectural projects. Artificial intelligence is particularly involved in tasks such as material recognition, scene lighting, and automatic adjustment of environmental details based on weather conditions. New plugins like AI Artist Styles allow visual outputs to be transformed into either artistic or photorealistic representations according to user preferences (EIN Presswire, 2025).

3.7 Enscape: Real Time Presentation and Lighting Analysis with Artificial Intelligence
Enscape operates in integration with software such as Revit, Rhino, ArchiCAD, and SketchUp to provide real-time rendering and virtual reality (VR) experiences. Artificial intelligence contributes primarily through automatic enhancements in light distribution, shadow analysis, and material interactions (Moldovan, 2024). Additionally, it features a system infrastructure that learns users' frequently applied visual settings and recommends them in future scenes.

3.8 Twinmotion: AI Supported Rapid Visualization and Interactive Scene Generation
Twinmotion is a visualization platform based on Unreal Engine. With AI support, many scene elements such as the automatic arrangement of environmental components, traffic density simulation, and weather scenario modeling can be generated without manual user input. Additionally, features such as sound synchronization and human movement animations are also automated by artificial intelligence (EIN Presswire, 2025).

3.9 SketchUp and Veras AI
SketchUp is a practical modeling tool commonly used for architectural concept design. Its functionality can be expanded through various plugins. In particular, Veras an AI-supported rendering engine enhances drawn objects with artistic or photorealistic renderings. Based on the user's stylistic preferences, Veras provides suggestions and generates scene specific variations through generative artificial intelligence (EvolveLAB, 2025).

Each of the software and plugins discussed in detail above illustrates how artificial intelligence is integrated into the architectural design process and the specific functional domains in which it contributes. The AI capacity, intended use, and the level of design support provided by each program vary considerably. This diversity necessitates that architects select the most appropriate digital tool based on project specific needs, thereby making design decisions more strategic. The comparative table below (Table 1) summarizes the modes of AI integration in the mentioned software and presents their contributions to the design process alongside their functional focus areas.

Table 1. AI Extensions in Architectural Drawing Software and Their Key Application Areas

Software	AI Extension / Module	Key Application Area
AutoCAD	Autodesk Assistant, Smart Blocks	Automated command suggestions, error detection
Revit	Generative Design	Plan variations, design optimization
Rhino + Grasshopper	Wallacei, Opossum, Dodo	Parametric modeling, evolutionary algorithms
Fusion 360	Generative Design	Fabrication oriented component design
Sefaira	AI based energy simulation	Daylighting, energy efficiency analysis
Lumion	AI Styles, Smart Lighting	Scene automation, realistic visualization
Enscape	AI Light Adjustment, Auto-materials	Lighting simulation, rendering optimization
Twinmotion	AI Landscape/Environment Builder	Interactive scene creation, environmental animations
SketchUp	Veras (EvolveLAB)	Conceptual visualization, AI-powered rendering

4. Application Areas and Advantages of AI-Supported Design Processes

The integration of artificial intelligence technologies into architectural drawing software represents not merely a technical transformation, but a holistic paradigm shift that reshapes the theoretical structure of architecture, decision-making processes, and professional practice. Traditionally guided by intuition, experience, and aesthetic judgment, the architectural design process has evolved into a data driven, computational, and automation-supported form. AI-assisted software stands at the core of this transformation, acting as an interactive solution partner for architects in tasks such as form generation, analysis, scenario development, and presentation preparation.

In this section, the contributions of AI integration to architectural design processes are evaluated under five main application areas: generative design and optimization, energy performance and sustainability analysis, visualization and presentation, decision support systems, and collaborative/learning environments (Table 2). These areas enhance both the technical and creative capacities of architects, enabling the development of more sustainable, rapid, error-free, and high quality projects.

Generative Design and Optimization: One of the most prominent areas where AI stands out in architectural processes is generative design. This approach allows for the creation of numerous design alternatives according to predefined goals and facilitates the identification of the most optimal solution. Tools such as Revit's Generative Design module, Wallacei and Opossum in Rhino+Grasshopper, and Fusion 360's generative design infrastructure are prominent in this field. For instance, when designing an office plan, the user can define criteria such as spatial efficiency, daylight duration, and user density, and the system generates optimized solutions based on these inputs. This enables the architect to make performance based decisions alongside aesthetic considerations (Turrin et al., 2011). These systems not only generate forms but also encourage the user to understand the mathematical rationale behind design decisions. In this way, AI transforms architectural design from a purely graphical process into a data-driven problem-solving practice.

Energy Performance and Sustainability Analysis: Sustainability has become one of the core principles of contemporary architecture and is considered a parameter that must be addressed from the earliest design stages. AI-supported simulation software provides substantial ease in this regard. Tools like Sefaira analyze performance data related to natural lighting, energy consumption, shading, and thermal comfort, offering real time feedback to architects on the environmental impact of their designs. In this way, energy modeling can be conducted even before construction, and cost performance forecasts can be developed. Furthermore, the system can test different design scenarios based on user inputs to determine the most efficient form. This process yields results that are significantly faster, more accurate, and measurable than traditional trial and error methods.

Visualization, Presentation, and Communication: Architecture not only involves designing but also effectively communicating the design. AI supported visualization software offers time and quality advantages to architects in this regard. Platforms like Lumion, Enscape, and Twinmotion can automatically adjust lighting conditions, optimize material reflections, and create scenes based on environmental factors using AI algorithms to produce highly realistic renderings. Additionally, generative AI extensions such as Veras contribute creatively to the design process by transforming basic sketches into meaningful conceptual designs. These systems serve as effective communication tools, especially in early design stages, when conveying ideas to clients or juries. The visual qualities of a design can thus be tested not only in terms of form but also perceptually and psychologically (Turrin et al., 2011).

Decision Support Systems and Error Reduction: AI has enabled the development of systems that can suggest commands based on user behavior, detect drawing errors in advance, and reduce repetitive tasks. Features like Smart Blocks and MyInsights in AutoCAD enhance the architect's efficiency while significantly reducing the margin of error, especially in large scale projects. These systems continuously monitor the user to learn common mistakes, offer suggestions, and automate the process. As a result, the architectural production process becomes not only faster but also improved in terms of quality and consistency. These software tools, which evolve from mere information users to systems that learn and develop, can be considered digital design partners providing cognitive support.

Table 2. Application Areas of AI-integrated Design Software in Architecture

Application Area	Software Examples	AI Contribution
Design & Modeling	Revit, Fusion 360, Rhino + Grasshopper	Producing alternative solutions, parametric optimization
Energy & Sustainability	Sefaira, Revit Insight	Performance analysis, energy modeling, environmental scenario generation
Visualization & Presentation	Lumion, Twinmotion, Enscape, Veras	Real-time visualization, lighting and material adjustment, render optimization
Decision Support / Error Reduction	AutoCAD (Smart Blocks, Assistant), Revit	Error detection, command suggestion, data-driven design guidance
Collaboration & Education	Hypar, Grasshopper	Real-time multidisciplinary teamwork, parametric design education

Collaboration, Educational Use, and Interdisciplinary Integration: Cloud based AI supported platforms (e.g., Hypar) enable multi-user interaction, turning design into a collective process. These environments allow users from different disciplines to work simultaneously on the same project while also facilitating the educational transmission of parametric thinking. Especially for architecture students, such platforms are highly functional for experiencing AI-based modeling strategies and developing algorithmic thinking skills. Thus, architectural education is transformed from a static knowledge transmission process into an experiential and generative learning environment.

Given all these contributions, the integration of artificial intelligence into architectural software should be considered not only as a technical support element, but also as a paradigm shift that rebuilds the philosophy of design. Architectural design now relies not only on human creativity, but also on the capacity of machine intelligence to generate and analyze unlimited variations. Thanks to this integration, the architect can make more holistic, data-driven and future sensitive design decisions, and establish stronger links between user needs, environmental factors and technological possibilities.

5. Conclusions

The integration of artificial intelligence into architectural drawing software is reshaping not only how architects design but also how they think, analyze, and communicate spatial ideas. As demonstrated throughout this study, AI supported design tools have become central to a wide range of architectural processes spanning from generative form finding and environmental simulations to real time rendering and decision support. These tools not only accelerate the production process but also enhance the quality, adaptability, and sustainability of architectural outcomes.

The comparative review of widely used programs such as AutoCAD, Revit, Rhino+Grasshopper, Fusion 360, Sefaira, Lumion, Enscape, Twinmotion, and SketchUp reveals a landscape where AI is no longer a supplementary feature, but a core engine behind intelligent design solutions. AI algorithms today can simulate complex behaviors, optimize spatial configurations based on performance data, suggest context aware modifications, and even render visually compelling outputs with minimal human input. This shift enables architects to move beyond traditional trial and error methods, embracing predictive and data driven approaches that reduce error margins and encourage design innovation.

Beyond its practical benefits, AI’s growing influence is gradually redefining the professional identity of the architect. The role is expanding from that of a sole creator to a strategic decision maker who collaborates with intelligent systems. In this new paradigm, creativity is augmented not replaced by computation, and design becomes a process of human machine synergy. However, this transformation also brings challenges. Issues such as algorithmic transparency, data ethics, and the risk of over automation must be critically addressed. Furthermore, architectural education must evolve to incorporate AI literacy, equipping future architects not only with design sensibilities but also with computational fluency.

Looking ahead, the architectural profession stands at the threshold of a digitally enriched future, where artificial intelligence will play an increasingly decisive role in shaping spatial experiences. Future research should focus on developing open source, context aware, and user friendly AI design tools that support inclusive, sustainable, and culturally responsive architecture. In this evolving landscape, architects who embrace the collaborative potential of AI will be better positioned to navigate complexity and drive meaningful innovation in the built environment.

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Assessing the knowledge of BIM professionals and the need for theoretical BIM education

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Abstract. Building Information Modeling (BIM) has emerged as an indispensable tool within the Architecture, Engineering, and Construction (AEC) industry, offering powerful capabilities for digital project planning, coordination, and management. Despite its growing use, many professionals engaging with BIM software often lack a comprehensive theoretical understanding of its underlying concepts, workflows, standards, and broader benefits. This missing knowledge hinders the effective use of BIM, as familiarity with software tools alone is insufficient for leveraging its full potential. A solid grasp of theoretical foundations can empower professionals to better coordinate complex projects, reduce design and construction errors, improve interdisciplinary collaboration, manage data efficiently, and make informed decisions across all project phases. To investigate this knowledge gap, the present research utilizes a structured survey targeting BIM professionals in Türkiye. The study focuses on their conceptual understanding of core themes such as data management, interoperability, standard compliance, and lifecycle integration. The results reveal a substantial disconnect between practical software use and theoretical knowledge, with many participants depending primarily on informal learning pathways. This dependence often results in inefficiencies, miscommunication, and limited project performance and quality. The findings emphasize the urgent need for structured and standardized education in BIM theory at both academic and professional levels. Incorporating comprehensive BIM theory into curricula and certification programs can enhance strategic thinking, workflow coordination, and long-term project outcomes. Ultimately, closing this knowledge gap is vital for cultivating a more capable, collaborative, and forward-thinking workforce equipped to lead digital transformation within the rapidly evolving AEC industry.

Keywords: Building Information Modeling; BIM; Theoretical BIM Education; Knowledge-based BIM Education; Digital Construction

1. Introduction

The construction industry plays a pivotal role in shaping economic activity and supporting numerous other industries. To enhance its efficiency and long-term value, the industry increasingly relies on digital tools and data-driven processes. One of the most transformative developments in this context is Building Information Modeling (BIM). The ISO 19650-1 standard refers to it as a "shared digital representation used to facilitate the entire life cycle of a building." Sinclair (2014) defines BIM as "the process of managing information in a three-dimensional model containing data related to a building's construction." This process serves as a tool applicable not only during the design phase but also throughout the construction phase and beyond.

BIM should not be considered merely as a software application. It represents a paradigm shift from traditional workflows by promoting a shared data environment where architects, engineers, contractors, and other stakeholders collaborate more effectively. Unlike conventional methods, where each party relies on separate and often incompatible tools, BIM fosters integration and communication across disciplines. It serves as a bridge between the architecture, engineering, and construction industries, enabling visualization before the construction phase, identifying potential issues early, and supporting time- and cost-efficient project delivery.

Recognized as a next-generation approach, BIM enhances productivity and streamlines the building delivery process (Qian, 2012). Its multidimensional framework—ranging from 3D modeling to 7D facility management and beyond—combined with information integration technologies, allows stakeholders such as government agencies, property owners, construction managers, and designers to access and manage comprehensive project data throughout the lifecycle (Li et al., 2014). Ultimately, BIM is a collaborative, multidimensional methodology that spans a wide professional domain.

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With BIM becoming mandatory for large-scale construction projects in many countries, it is crucial for all industry stakeholders to develop a clear understanding of this technology. However, the successful adoption of BIM is often hindered by the high costs associated with skill development, training programs, and management processes. Studies indicate that these challenges represent some of the most significant barriers to widespread BIM implementation (Khosrowshahi & Arayici, 2012; Succar et al. 2013; McGraw Hill Construction, 2014) . To overcome these obstacles, acquiring fundamental BIM skills through structured education is essential. This not only reduces adoption costs but also enhances career opportunities for architecture, engineering, and construction professionals.

BIM is particularly critical for the Turkish construction industry, which must align itself with global advancements. Understanding the current state of BIM adoption in Türkiye and implementing effective strategies for its integration are key priorities. However, BIM education in Türkiye remains limited and lacks standardization at the academic level. There is a pressing need to develop comprehensive BIM training programs covering theoretical foundations, terminologies, methodologies, and the necessary digital infrastructure.

Recognizing these gaps and the urgency for action, the Ministry of Environment and Urbanization took a significant step by issuing the memorandum titled "Inclusion of Building Information Modeling (BIM) Courses at Undergraduate/Graduate Levels," on October 8, 2021 (T.C. Çevre ve Şehircilik Bakanlığı, 2021). Through this initiative, the Ministry launched efforts to develop innovative national strategies and related regulations aimed at the digital transformation of the Turkish construction industry. The memorandum states that it is planned for all construction and operation processes, from the design phase to the end of a building's lifecycle, to be conducted using BIM. Furthermore, it emphasizes that one of the most critical steps to ensure BIM integration in public institutions, organizations, and the private industry is for universities to train academics in these fields, update their curricula, and educate qualified technical personnel. Through the decision formalized by this memorandum, the importance of adopting the BIM concept at an early stage is also supported and prioritized by public institutions.

Building upon these efforts, a significant regulatory development was introduced with the amendment to the Regulation on Planned Areas (T.C. Resmi Gazete, March 11, 2025). According to this amendment, for projects designated by the Ministry, it has become mandatory to store project documents, drawings, calculations, and reports related to construction permits in a digital environment in accordance with BIM standards. These documents will be recorded, reviewed, approved, and archived electronically within the Ministry's or authorized bodies' digital infrastructure systems, eliminating the requirement for printed documents during these procedures. This legislative change marks a pivotal step toward accelerating the widespread adoption of BIM in Türkiye, further solidifying its role in the country's ongoing digital transformation in the construction industry.

2. Research Rationale

The research rationale of this study centers on the critical need to integrate a theoretical foundation of Building Information Modeling (BIM) into architectural and engineering education as well as professional training programs, especially within the Turkish construction industry. As explained in the earlier section, BIM represents a transformative innovation in the construction industry, facilitating interdisciplinary collaboration through a shared three-dimensional modeling environment. Despite its increasing global adoption, BIM education in Türkiye remains inadequate, lacking widespread standardization and comprehensive theoretical coverage. This insufficiency is reflected in the limited understanding of BIM concepts, terminologies, logic, innovations, and its adaptable infrastructure among professionals, which hinders effective BIM utilization and adoption in practice

This study identifies that while BIM software skills and process-specific training are common, there is a significant gap in imparting the conceptual and theoretical knowledge necessary for a holistic understanding of BIM. Such theoretical knowledge is essential not only for grasping BIM's operational tools but also for fostering critical thinking, organizing information logically, and adapting to technological advancements in the field. The absence of this foundational knowledge can lead to suboptimal BIM implementation, increased errors, and inefficiencies in construction projects

Moreover, the demand for BIM-competent personnel worldwide has surged, yet the shortage of individuals with adequate BIM theoretical knowledge remains a major barrier to BIM adoption. This gap is particularly pronounced in Türkiye, "where BIM education is still new and not yet well-organized. Thus, establishing the necessity for a structured, conceptual BIM education tailored to the industry's needs is vital for enhancing BIM competence, reducing adoption costs, and improving career prospects for graduates and professionals in architecture, engineering, and construction disciplines.

This research further rationalizes that a theoretical BIM education grounded on internationally recognized standards and learning outcomes, such as those published by buildingSMART, would provide a robust framework for curricula development (buildingSMART, 2018). By aligning educational content with these outcomes, it becomes possible to systematically address the educational deficiencies identified through both literature reviews and empirical data gathered via industry-wide surveys. These surveys assess current theoretical BIM knowledge among Turkish construction professionals, revealing critical gaps in areas such as BIM maturity levels, standards, information exchange requirements, common data environments, and BIM execution plans.

In summary, the research rationale is based on the recognition that effective BIM adoption and utilization in the Turkish construction industry require a foundational theoretical understanding that is currently lacking. This study aims to fill that gap by demonstrating the need for conceptual or knowledge-based BIM education, identifying the critical content areas for such education, and providing a basis for future curriculum development and sectorial capacity building. The study's findings and methodology can serve as an essential reference for educators, professionals, and policymakers aiming to enhance BIM competence and promote innovation in the construction industry.

2. Materials and Methods

2.1. BIM Education Types

The increasing importance of Building Information Modeling (BIM) in architecture, engineering, and construction has led to the emergence of diverse educational strategies aimed at equipping future professionals with both conceptual and practical competencies. BIM education typically follows two parallel pathways: academic programs centered on conceptual foundations and professional training that emphasizes technical application. Each pathway serves different purposes and caters to distinct audiences, yet both contribute to the widespread implementation and understanding of BIM.

Academic programs often approach BIM as a multidisciplinary concept and seek to embed it within architecture, engineering, and construction curricula. At many universities, particularly at the postgraduate level, BIM is incorporated not only as a software tool but as a process-oriented framework involving standards, information workflows, and lifecycle thinking. Cardiff University, for instance, offers a master's degree in Smart Engineering focusing on infrastructure modeling, incorporating subjects such as information requirements, project delivery plans, and data environments (Cardiff Univ., n.d.). Similarly, the University of Minho's BIM A+ program emphasizes information management, collaboration, 4D–6D modeling, and sustainability analysis across six specialized courses (Univ. of Minho, n.d.). These programs reflect a pedagogical commitment to aligning technical skills with conceptual knowledge and collaborative workflows.

Private institutions also contribute significantly to the development of BIM competencies. The Zigurat Institute's "Global BIM Management" master's program, delivered entirely online, serves industry professionals seeking leadership roles in digital construction. This program presents BIM not just as a modeling tool, but as a holistic management strategy, with topics including coordination, cost planning, and asset management (Zigurat Institute, n.d.). The Graphisoft BIM curriculum, designed for educators, offers a comprehensive instructional package focusing on design collaboration, sustainability, and documentation using ArchiCAD (Graphisoft, n.d.).

In Türkiye, universities and continuing education centers have started offering programs with increasing depth. The "Architectural and Urban Informatics" master's degree at Mimar Sinan Fine Arts University (MSGSU) introduces students to BIM from a theoretical standpoint, emphasizing the relationship between design and information systems. This curriculum includes courses on sustainable modeling, project integration, and GIS-BIM interoperability, offering students both theoretical and practical grounding (MSGSU, n.d.). Complementary to this, MSGSU and ITU's continuing education centers provide certification programs for BIM operators and specialists. These shorter, modular programs focus on project delivery, document control, software proficiency, and model coordination, aiming to meet the immediate needs of professionals (ITU SEM, n.d.). For example, the MSGSU SEM BIM Operator course blends theoretical instruction with applied learning, addressing ISO standards, sustainability analysis, and HVAC modeling tools.

Comparative reviews of international and Turkish programs reveal a strong emphasis on software training and industry-specific needs, while deeper conceptual content remains underrepresented. A cross-analysis of 11 programs found that over 90% covered topics such as BIM software, standards, collaboration, and data environments. However, more abstract elements like BIM maturity levels, schema development, and data security were included in less than 20% of the programs (Şen, 2022). These findings underscore the continued prioritization of tool-based instruction over conceptual integration, despite growing recognition that a balanced curriculum should cover both. Researchers such as Wu and Issa (2014) have shown that while industry professionals value software skills, long-term BIM effectiveness requires understanding the processes and frameworks that underlie the technology. This sentiment is echoed by Sacks and Pikas (2013), who argue that conceptual fluency is more sustainable than tool mastery alone, given the evolving nature of BIM platforms.

Nonetheless, many institutions face challenges in transforming curricula. Surveys show that over 70% of BIM educators in the U.S. are adjunct or contract-based faculty, largely due to resistance from tenured faculty to adopt new technologies and revise established courses (Joannides et al., 2012; Sharag-Eldin & Nawari, 2010). Most instructors were trained in CAD environments, creating a generational gap in BIM fluency (Suwal et al., 2014). These obstacles point to a need for professional development initiatives that can align teaching capacity with industry expectations. Collaborative efforts like Li et al. (2013) industry-supported design workshops and curriculum development seminars of Suwal (2013) have proven to be successful models for advancing BIM instruction.

At the policy level, countries that have mandated BIM usage in public projects, such as the United Kingdom, Norway, and Singapore, have observed a direct increase in BIM training programs and national standard-setting initiatives. The UK's 2011 Government Construction Strategy, which mandated BIM Level 2 for public projects was a catalyst for educational reform and professional certification in the country (Government, 2012). Organizations like the BIM Academic Forum (UK), the Academic Interoperability Coalition (US), and New Zealand's NBEWG (New Zealand National BIM Education Work Group) have also supported the development of standardized curricula and learning outcomes in response to national strategies.

In conclusion, the current landscape of BIM education reveals a dynamic yet imbalanced emphasis: while software training and industry-driven content dominate course offerings, foundational understanding of BIM's conceptual underpinnings remains limited. This gap emphasizes the need for educational models that treat BIM not merely as a technical tool but as a collaborative, data-driven methodology that reshapes the construction process. As the demand for digitally literate professionals grows, both academic institutions and industry actors must work together to ensure that BIM education evolves in both depth and scope.

2.2. buildingSMART BIM Training

buildingSMART is an internationally recognized non-profit organization that leads the development of openBIM standards and promotes interoperability in the built environment. In response to persistent confusion surrounding BIM processes and terminology, buildingSMART established a global Professional Certification (pCERT) Program, aiming to standardize BIM-related competencies and provide a consistent benchmark for evaluating industry professionals worldwide.

Central to this initiative is a framework of Basic Learning Outcomes, grouped into five thematic areas encompassing 28 specific competencies. These outcomes include foundational knowledge such as defining BIM, understanding its necessity, recognizing key openBIM standards and ISO19650 terminologies (e.g., EIR, BEP, CDE, COBie), and interpreting BIM maturity levels from Level 0 to Level 3. The curriculum also highlights the value of BIM in contrast to traditional project delivery methods, focusing on its role in improving collaboration, information accuracy, and lifecycle management, while mitigating the risks of poor information handling (buildingSMART, n.d.).

A key component of the certification process is the Body of Knowledge (BoK), which outlines the educational content to be covered in formal training. Upon completing a certified course, participants must pass a standardized online exam developed by buildingSMART to obtain the official buildingSMART Professional Certification. This certification program is also actively implemented in Türkiye through buildingSMART Türkiye, the Turkish chapter of buildingSMART International (buildingSMART Türkiye, n.d.). The same Body of Knowledge, translated and localized for Turkish professionals, forms the basis of training and examinations offered within the country. Notably, this research study was conducted between June 2021 and January 2022, just before the implementation of the education program by buildingSMART Türkiye.

Globally, the buildingSMART certification is increasingly recognized as a mark of BIM competence. In Germany, for example, the certification is often referenced in public procurement documents and is used as a formal credential in professional qualification frameworks. Similarly, in countries like the UK, Norway, and the Netherlands, the certification aligns with national digital construction strategies and is supported by both public authorities and large private firms as a reliable indicator of openBIM proficiency. Its alignment with ISO 19650 and international interoperability frameworks adds further value for professionals working in multinational or collaborative digital environments.

In summary, buildingSMART's education and certification program plays a transformative role in elevating BIM literacy across the AEC industry. By offering a structured, internationally accepted framework that blends conceptual clarity with technical precision, and through national chapters like buildingSMART Türkiye, it enables professionals to engage meaningfully in digital workflows, both locally and globally.

2.3. Methodology

This study employs a survey-based research design to assess the necessity of Building Information Modeling (BIM) education in the Turkish construction industry and to evaluate the extent to which professionals comprehend core BIM concepts. Given the critical importance of informed and capable stakeholders for the successful implementation of BIM processes, the research focuses on measuring foundational knowledge among practitioners currently involved in BIM-related roles.

The survey instrument was developed in alignment with the buildingSMART Professional Certification Program, specifically drawing from the open-access document Phase 1: Individual Qualification – Overview and Sponsorship Plan. In particular, the survey questions were structured according to Section 3.6 of this document, which outlines 28 Basic Learning Outcomes grouped under five competency categories: (1) understanding what BIM is and why it is necessary, including its terminology; (2) recognizing the benefits of BIM over traditional project delivery; (3) understanding the project information development cycle and related key terms; (4) acknowledging the need for open and interoperable solutions; and (5) assessing an organization's capacity to work with BIM. While the survey questions are structured according to these categories, they do not entirely encompass the full scope of their content.

The primary goal of the survey was to determine whether professionals actively engaged in BIM-related roles possess a basic level of conceptual knowledge as defined by buildingSMART. The survey also sought to reveal whether there is a need for further structured, knowledge-based education in Türkiye. While the survey addresses fundamental concepts, it may contain content that exceeds the expected expertise of individuals who have never received formal BIM education or participated in structured BIM processes.

Due to limitations caused by the COVID-19 pandemic, the survey was distributed in digital form via Google Forms to facilitate participation. The link was sent through email, and follow-up reminders were issued at 10-day intervals for non-respondents. The final version of the questionnaire consisted of 20 multiple-choice questions, each with a single correct answer, mirroring the structure of buildingSMART's actual certification exam (Table 1). In addition, two open-ended questions were included: one to gather participants' views on the value of theoretical BIM education, and the other to collect their suggestions. To obtain a realistic measure of BIM knowledge within the industry, the survey specifically targeted construction professionals who have experience with at least one BIM project. Participants were selected from individuals holding the roles of BIM Manager or BIM Operator, which are among the most essential positions within BIM teams. According to Baldwin (2021), BIM Managers oversee internal BIM teams, supervise CAD/BIM processes, ensure project compliance with the BIM Execution Plan (BEP), lead quality control, and coordinate among disciplines. BIM Operators are responsible for producing and managing model data, performing analyses and documentation, and supporting coordination and reporting tasks.

To achieve a balanced dataset, the sample was designed to reflect a 1:2 ratio of BIM Managers to BIM Operators, representing a typical BIM team structure consisting of one manager and two operators. In consideration of the limited extent of BIM adoption in Türkiye, the survey was sent to a total of 90 professionals. Ultimately, 40 valid responses were collected. Among the respondents, 12 (30%) identified as BIM Managers and 28 (70%) as BIM Operators. While gender distribution data was collected (12 BIM Managers: 7 male, 5 female; 28 BIM Operators: 14 male, 14 female), this was not used in the analysis, as gender was not within the scope of the research objectives.

Table 1. Survey Questions

No	Question
Q01	Which of the following is not one of the primary factors promoting the use of BIM?
Q02	Which of the following is not covered by the BS 1192 standard, which is described as a Code of Practice?
Q03	Which of the following is the full form of the term EIR?
Q04	Which of the following is not one of the components of an EIR?
Q05	The sharing of information produced by organizations in a structured format—based on agreed standards, methods, and procedures—with project teams through a Common Data Environment (CDE) is considered to fall under which level of BIM Maturity?
Q06	Which of the following is the BIM Maturity Level that was mandated by the government in the UK in 2016?
Q07	In project processes, which of the following must the Appointing Party determine first?
Q08	At which stage within project processes is it recommended to establish the Common Data Environment (CDE) in organizations?
Q09	Which of the following is not one of the sub-information areas of the Common Data Environment (CDE)?
Q10	Which of the following is not considered part of the openBIM category?
Q11	Which of the following standards focuses on the use of assets in operational processes within BIM workflows?
Q12	Which of the following cannot be given as an example of the benefits of BIM adoption?
Q13	Which of the following is not one of the main challenges in BIM adoption?
Q14	Which of the following best describes the concept of openBIM?
Q15	Which of the following is not true about buildingSMART?
Q16	Which of the following is the plan that explains how the information management aspects of appointments will be carried out by the delivery team in response to the EIR requirements?
Q17	Which of the following is not a part of an information model?
Q18	Which of the following is the name given to the information model during project delivery processes?
Q19	Which of the following is the guideline primarily used by advanced technical users or software developers, defined as a methodology for identifying and documenting business processes and information requirements—that is, standard BIM activities?
Q20	Issues related to spatial coordination, site inspections, or clashes that arise can be easily communicated using which of the following, instead of a long email chain?
Q21	Have you received any conceptual training on the theories, standards, and protocols related to BIM? Do you consider such training necessary? Why?
Q22	Other comments and suggestions

3. Results and Discussion

The survey identifies the topics that are lacking or not well understood in the industry by individually evaluating the 20 multiple-choice questions designed to measure the general level of BIM knowledge among participants (Table 2).

Most BIM Operators have 1–5 years of experience. The majority of BIM Managers, on the other hand, have 4–5 years of experience. These durations reflect the participants' working time under the specified titles. It was found that 80% of the participants had previously received some form of BIM education. In response to the open-ended question about the type of training, most participants cited graduate-level programs, individual certification programs, and in-house training. Undergraduate-level education appeared to be the least common.

When evaluating the responses of all participants, the overall average success rate remained around 50% and did not exceed the average threshold. For the 12 participants with the title of BIM Manager, the average success rate was determined to be 57.9%. For those with the title of BIM Operator, the average success rate was 47%.

As part of determining and evaluating the success rates of the survey questions, the success rates of all 20 multiple-choice questions designed to assess BIM knowledge were examined in the graph presented in Fig. 1. As shown in the graph, 10 of the survey questions (marked in green: questions 1, 4, 6, 7, 9, 14, 15, 17, 18, and 20) were answered correctly by 50% or more of the participants. The remaining 10 questions, however, fell below the 50% success threshold, which is considered the average level of BIM proficiency for the Turkish construction industry (marked in red: questions 2, 3, 5, 10, 11, 12, 13, 16, and 19).

Following the evaluation of all survey questions, the distribution of success rates between participants with the titles of BIM Operator and BIM Manager was also examined in detail. The two resulting graphs (Fig. 2 and Fig. 3) indicate that the overall average was slightly lower by the responses of participants in the BIM Operator role.

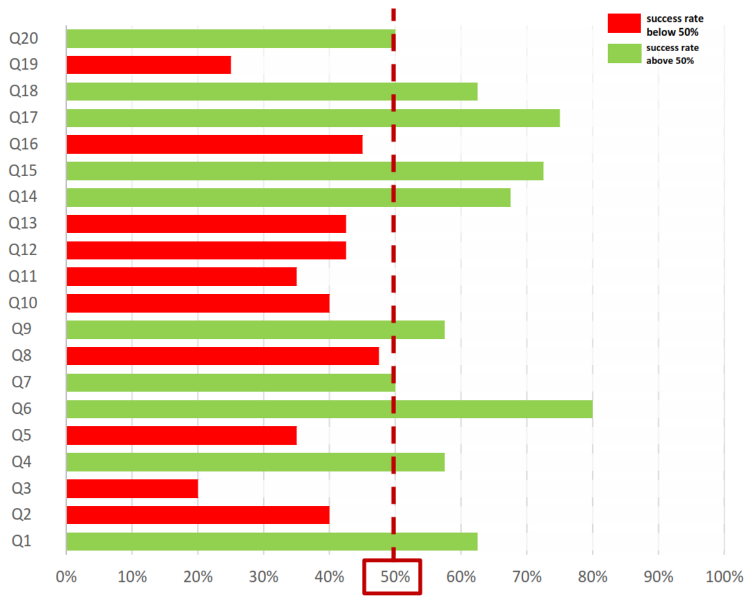

Fig. 1. Correct response rate for the survey questions

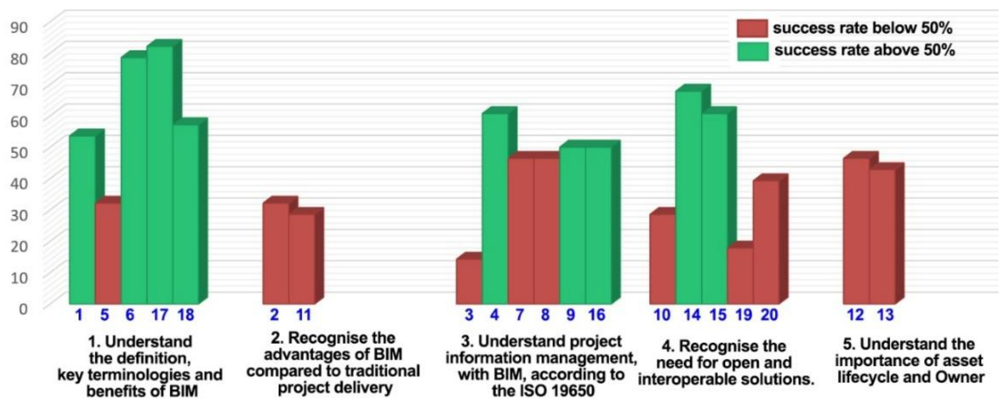

Fig. 2. Graph showing the success rates of survey questions among participants with the role of BIM Operators

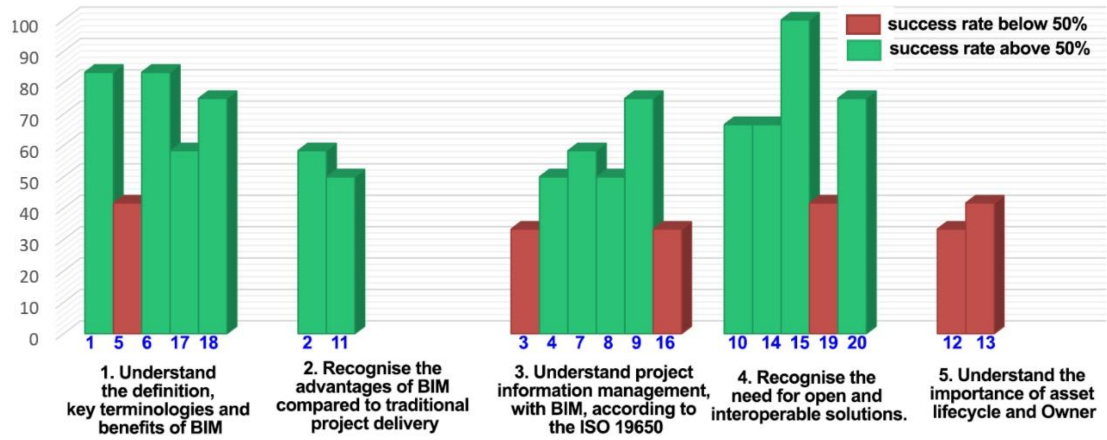

Fig. 3. Graph showing the success rates of survey questions among participants with the role of BIM Managers

3.1. Survey results by topics

When all the collected data is examined, it is observed that the questions with a success rate above 50% fall under the following topics: drivers of the BIM concept, Exchange Information Requirements (EIR), BIM Maturity Levels, Common Data Environment (CDE), openBIM, buildingSMART, Information Model, Project Information Model (PIM), and BIM Collaboration Format (BCF).

The topics that fell below the 50% success rate were identified as follows: BIM Standards, Exchange Information Requirements (EIR), BIM Maturity Levels, Common Data Environment (CDE), openBIM, Benefits and Challenges of BIM Implementation, BIM Execution Plan (BEP), and Information Delivery Manual (IDM).

Among all the collected data, it was observed that four topics appear both among those with a success rate above 50% and among those below 50%. These topics are: Exchange Information Requirements (EIR), BIM Maturity Levels, Common Data Environment (CDE), and openBIM. This indicates that participants do not demonstrate full competency in these areas, yet the topics also cannot be classified as clearly lacking. These four ambiguous areas should be treated with the same level of importance as those below the 50% success threshold and should be addressed further.

Considering these findings, it becomes evident that BIM lacks conceptual clarity in various processes where it is applied within the industry. While the existence of knowledge is reflected in success rates close to the average, the evaluation of participants' understanding based on the Basic Learning Outcomes reveals notable deficiencies. These shortcomings can be attributed to factors such as misinterpretation of terminology, lack of awareness of up-to-date information, and a practice-oriented approach focused solely on problem-solving during implementation phases.

In light of these issues, identifying the deficient areas—whether in academic institutions or within firms—and developing theory-based BIM training programs tailored to those needs would help address the gaps in current educational systems. The wide range of educational sources, such as academic programs, certifications, and software training, which professionals rely on to build their competencies, may be contributing to conceptual confusion within the industry. Therefore, defining BIM terminology and its theoretical foundation, and offering a structured conceptual BIM education to the industry is essential. The knowledge gaps revealed through the survey and the feedback provided by professionals from the Turkish construction industry strongly support this need.

As with any discipline, the most effective way to learn and apply knowledge in the field of BIM is not through superficial solutions but through a solid conceptual foundation. A theory-based BIM education is one of the essential building blocks for constructing such a foundation.

3.2. The value of theoretical bim education through the review of the open-ended question

Out of the 40 professionals who participated in the survey, 35 responses supported the necessity of a conceptual BIM education, with several participants stating that this survey helped them recognize their own knowledge gaps and emphasized the importance of conceptual training, which is considered one of the positive outcomes of the study. Among all comments, only one participant stated that they had not received any conceptual BIM training and did not find it necessary. Although personal details were not disclosed, it was noted that this participant had previously received BIM training, had over five years of experience working as a BIM Operator, and provided responses at around the average level. In four responses, participants chose not to answer this specific question. These individuals' overall survey scores were either average or below average.

Participants responded to the final open-ended qualitative question, which asked: "Have you received any conceptual education regarding the theories, standards, and protocols related to BIM? Do you think such training is necessary? Why?"

Upon reviewing the responses, it was observed that the comments clustered around certain themes. These themes, insights, and participant opinions were analyzed by grouping respondents into two categories: those who had previously received BIM training and those who had not. Among participants who had not received any prior BIM education, the most frequently mentioned issue was the existence of conceptual confusion regarding BIM within the industry. These participants expressed the view that a theory-based BIM education is necessary in order to resolve this confusion.

- *"BIM does not only mean modeling. One must also learn its underlying structure and processes."*
- *"I believe training is necessary to eliminate conceptual confusion."*
- *"... such training is necessary. Otherwise, it's hard to understand why a large amount of information needs to be integrated into the model."*

Based on the comments provided by the participants, it is apparent that a theory-based BIM education is considered beneficial for understanding standards. A few of the relevant comments received in this regard are listed below:

- *"I believe receiving such training would be beneficial for understanding BIM within the framework of standards and protocols."*
- *"I have not received a qualified education regarding theory, standards, and protocols. I have only participated in general informative sessions. Confronted with the survey questions, I realized how much I lacked knowledge and how necessary such training is."*
- *"While working on a project that follows BIM standards, I believe it is essential to be familiar with the standards and protocols in order for the process to run smoothly. In this regard, receiving such training would have been valuable."*

At this point, the inclusion of standards as a core topic in a theory-based BIM education is supported as a factor that would have a positive impact. Participant feedback also suggests that a theory-based BIM education would be beneficial for promoting the use of BIM within the framework of interoperability, enhancing its applicability, and improving its management.

- *"I believe such training is necessary for professional BIM use and coordination."*
- *"I haven't received conceptual training, but I see it as essential. This way, the logic behind the work can be understood, and a common language can be established among collaborators."*
- *"Since conceptual training forms the basis of communication, it is essential for a healthy and clear data exchange."*
- *"I haven't received any conceptual training. I think it's necessary in order to better understand BIM-related resources and to apply them in projects. It will also accelerate BIM processes."*
- *"... I believe BIM theory should be gradually and accessibly integrated into the industry. Especially since the benefits gained from practice give more meaning to its theory, I think a balanced adaptation process is needed."*

Among the participant comments, there are also remarks indicating that this study has raised awareness regarding the need for a theory-based BIM education. Some of these comments include:

- *"I struggled a lot while answering the questions. I haven't received training on these kinds of conceptual topics, but I now realize there's so much I didn't know."*
- *"Through this study, I realized that I need to receive such training."*
- *"... I haven't received any training. However, after completing this survey you prepared, I've come to understand that such education is essential. ... Simply knowing a few software programs is not enough to be part of the BIM system. Just as a building needs a foundation, regulations and theoretical knowledge are the foundation of every system."*

When examining the responses from participants who had previously received BIM training, it is observed that topics related to BIM processes, workflows, and the management of these processes come to the forefront.

- *"It is necessary to receive training; BIM processes and management are a form of project and process management independent of software tools."*
- *"In order to properly understand and manage BIM processes, all project stakeholders must have knowledge of its theory, standards, and protocols. This knowledge can be acquired through training."*
- *"Since both the concepts and workflow models are very new to most professionals in the field, I absolutely believe that training is necessary."*

Another point on which the comments from participants who had previously received BIM training tend to cluster is sectoral needs, goals, and expectations. Within this context, some participants expressed the belief that the goals to be determined for the industry can be achieved through proper training.

- *"I believe that training will lead to more informed, more economical, and more efficient construction processes."*
- *"Yes, I consider training necessary. If the concepts are not well understood, I don't think BIM implementations can reach a level that meets goals and expectations."*
- *"I have mostly received technical training, but I also believe conceptual training is necessary. I think it's essential to understand the concepts and standards in order to properly define the needs."*

4. Conclusions

This study has confirmed that Building Information Modeling (BIM) is not only a technological shift but also a transformative process that necessitates the redefinition of education within the construction industry. A key argument throughout the research is that without proper training, particularly at the conceptual level, the full potential of BIM cannot be realized. An in-depth examination of both international and national BIM education programs, alongside a detailed analysis of existing standards such as BS-PAS 1192 and ISO 19650, has revealed substantial gaps in the theoretical content currently being delivered. Topics such as BIM Maturity Levels, Exchange Information Requirements (EIR), Common Data Environment (CDE), openBIM, and the BIM Execution Plan (BEP) were consistently underrepresented in existing curricula, despite being critical for effective BIM implementation.

Using the buildingSMART Professional Certification's Basic Learning Outcomes as a reference, a structured survey was developed and administered to 40 professionals working as BIM Operators and BIM Managers in the Turkish construction industry. The results revealed that most participants were unable to achieve a success rate above 50% on key conceptual questions, and the feedback clearly indicated a demand for structured, theoretical BIM training. Notably, many professionals acknowledged through the survey that they had previously underestimated the importance of conceptual education, and realized their own knowledge gaps during participation. The comments collected from industry professionals, who acknowledged the survey as a turning point in recognizing their educational needs, add further weight to the study's conclusions.

The findings of this research strongly support the urgent need to integrate theory-based BIM education, either as part of postgraduate programs or through professional training offered by certified institutions and continuous education centers. Furthermore, the study emphasizes the importance of qualified instructors who can act not only as knowledge providers but also as facilitators of critical thinking and project-based learning.

In summary, the research demonstrates that a comprehensive, conceptual BIM education is not only necessary but vital for advancing BIM integration in the Turkish construction industry. The study provides a foundational reference for future curriculum development and highlights the importance of early and strategic investment in theoretical BIM literacy as a key driver for industry-wide digital transformation.

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Reframing circulation as a learning space: Non-Formal learning in the architecture schools of TU Delft and Cornell

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Abstract. This paper investigates the pedagogical potential of circulation spaces in architecture schools, proposing their reinterpretation as non-formal learning environments. Drawing on the tripartite classification of learning—formal, non-formal, and informal—it highlights how spatially and socially permeable environments can support self-directed, collaborative, and situated learning beyond the formal studio. The study emphasizes that circulation areas—such as corridors, atriums, and transitional spaces—can become integral to architectural education when designed or appropriated with pedagogical intent.Using a qualitative comparative case study methodology, the research analyzes two architectural education environments: the Faculty of Architecture at TU Delft and Cornell University's College of Architecture, Art, and Planning (AAP). These cases are examined through five key spatial criteria: visual openness, programmatic integration, social interaction potential, flexibility of use, and the balance between design intent and emergent behavior.Findings reveal that in both cases, circulation spaces transcend their conventional role as functional connectors. At TU Delft, the post-fire transformation of the Red Building led to the emergence of a "street" concept supporting collective production and exhibition. At Cornell, Milstein Hall's elevated and transparent studio slab integrates informal presentation platforms and spatial overlaps that foster peer-to-peer learning.The study argues that reframing circulation areas as pedagogically active zones enables a more inclusive, dynamic, and responsive learning ecosystem. It contributes a conceptual framework for integrating non-formal learning into architectural design education and offers strategic insights for future spatial planning in academic environments.

Keywords: learning environments; learning space; architecture education; non-formal learning; transitional space.

1. Introduction

In recent years, universities have been increasingly transforming into multidimensional learning environments that go beyond the traditional classroom. While formal educational activities remain central to curricula, a growing body of research highlights the role of non-formal and informal learning processes in fostering creativity, peer interaction and interdisciplinary engagement. Within this broader educational ecosystem, circulation spaces, including corridors, atriums, transit halls and connecting passageways, represent an often overlooked, yet spatially and socially significant category of spatial infrastructure.

Defined by their transitional function, circulation spaces are typically conceived to ensure the movement of people and the connection of programs. However, recent discussions in architectural pedagogy and learning space theory suggest that these in-between spaces may also foster meaningful forms of non-formal learning. They offer opportunities for spontaneous dialogue, informal collaboration, cross-disciplinary encounters, and unplanned moments of reflection—all essential to the formation of architectural thinking and community.

Despite their potential, circulation areas in educational buildings are rarely designed with pedagogical intent. As a result, their spatial configurations often fail to support the kinds of informal and semi-structured learning that contemporary educational models increasingly value. This paper seeks to address this gap by examining the educational role of circulation spaces in architecture schools, particularly in relation to non-formal learning environments—defined as learning contexts that are structured but not part of the formal curriculum, and that occur outside of traditional classroom settings.

The aim of this study is twofold: first, to synthesize the existing literature on circulation spaces and non-formal learning in architectural education; second, to present a comparative spatial reading of two prominent architecture schools—the Faculty of Architecture at Delft University of Technology (TU Delft) and Milstein Hall at Cornell

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University. Through this analysis, the paper discusses how circulation areas may be intentionally designed or reinterpreted as pedagogical tools that contribute to the learning ecosystem of architecture schools.

2. Theoretical Framework & Literature Review

2.1. Learning Spaces in Higher Education

Recent shifts in pedagogical paradigms emphasize the spatial dimension of learning, drawing attention to environments beyond the formal classroom. The tripartite classification of learning—formal, non-formal, and informal—has become instrumental in analyzing the diversity of educational settings. According to the OECD, formal learning is institutionally organized, curriculum-bound, and typically leads to certification(OECD, 2004). Non-formal learning occurs outside this framework but is still intentional and structured, while informal learning is unplanned, often arising through social interaction or environmental immersion. Colley et al., further assert that these categories exist along a continuum rather than as discrete types, and that overlapping characteristics often emerge in practice (Colley et al., 2003).

In the context of higher education, non-formal learning spaces have gained recognition for supporting student autonomy, interdisciplinary interaction, and peer-based knowledge construction (Ellis & Goodyear, 2016). Such environments allow for reflection, dialogue, and experimentation—key dimensions of deep learning (Brown et al., 2020). Architecture schools, with their emphasis on iterative design processes, critique culture, and studio-based pedagogy, particularly benefit from spaces that accommodate spontaneous and collaborative learning.

The shift toward "seamless learning environments"(Kuh, 1996), where learning transcends spatial and temporal boundaries, challenges educators and designers to reconsider the pedagogical role of transitional and informal spaces within university settings.

2.2 Circulation and In-Between Spaces in Architecture

From an architectural perspective, circulation spaces—including corridors, stairwells, atriums, and landings—have traditionally been seen as functional connectors rather than pedagogical domains. However, architectural theory has long interrogated the liminality and symbolic potency of such "in-between" or "threshold" spaces. Wigley and Tschumi frame these zones as spatial conditions that defy binary classifications of inside/outside, public/private, or static/dynamic. These interstitial spaces often embody openness, ambiguity, and social permeability—qualities that align with contemporary pedagogical values such as adaptability, participation, and serendipity. (Wigley, 1991) (Tschumi, 1996)

In the context of learning environments, these spaces support learning outside the confines of formal education and provide opportunities for informal encounters, interdisciplinary dialogue and reflective pause (Harrison & Hutton, 2014). Yet, despite their potential, they often remain under-conceptualized within institutional design strategies.

2.3 Rethinking In-Between Spaces as Non-Formal Learning Environments

While non-formal learning spaces and in-between spaces originate from distinct disciplinary vocabularies—educational theory and architectural theory, respectively—they exhibit substantial thematic convergence. Both prioritize flexibility, openness, and social interaction, and both are situated outside the formal curriculum or programmatic structure. The principal difference lies in intentionality: non-formal learning spaces are increasingly designed to support learning, while in-between spaces often emerge as by-products of circulation or zoning requirements.

Recent literature suggests that these spatial categories need not remain separate. Harrison & Hutton, argue that educational institutions should "design for serendipity" by enabling informal interaction and co-presence through spatial affordances (Harrison & Hutton, 2014),. Temple, similarly posits that transitional spaces can act as pedagogical instruments if designed to foster engagement and belonging (Temple, 2008).

This paper builds on these perspectives by proposing that circulation areas—often conceptualized as threshold or in-between zones—can be reframed as non-formal learning environments when designed or interpreted with pedagogical intent. By comparing two architectural school buildings—TU Delft and Cornell—this study aims to uncover how such reframing may occur spatially and what design principles underpin these transformations.

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3. Methodology & Case Selection

This study adopts a qualitative comparative case study methodology to investigate how circulation spaces in architecture schools function as non-formal learning spaces. Based on a spatial-pedagogical framework, the research aims to analyze not only the physical characteristics of these spaces, but also their designed affordances, social behavior and educational outcomes in the context of architectural education.

Case selection was based on pedagogical relevance, architectural distinction, and spatial comparability. Analytical criteria included spatial openness, social interaction potential, programmatic integration, design intent vs. emergent use, and pedagogical typology (formal, non-formal, informal).

While the lack of ethnographic fieldwork is a limitation, spatial-pedagogical interpretation allows for rich conceptual insights, forming the foundation for future field-based researchs.

4. Findings & Comparative Analysis

Circulation spaces in architecture schools are increasingly recognized not merely as connective infrastructure, but as potential sites of pedagogical activation. The spatial strategies employed by TU Delft and Cornell AAP illustrate two distinct yet complementary approaches to integrating non-formal learning into the architectural fabric of their institutions.

At TU Delft, the post-crisis renovation of the Red Building gave rise to a central "street" that reconfigures circulation as an active spatial spine. This corridor not only facilitates movement but also orchestrates social encounters, collaborative production, and exhibition. The integration of workshop zones, lounge areas, and informal seating along the street allows learning to emerge in a layered and unprogrammed manner.

In contrast, Cornell's Milstein Hall, designed by OMA, demonstrates a highly intentional insertion of learning-supportive functions into circulation. The cantilevered studio slab, with embedded informal presentation platforms and visual permeability, reflects a design agenda that seeks to expose and spatialize the act of learning itself. Circulation is not peripheral, but central to the performance of pedagogy.

Together, these cases highlight how circulation spaces—through varying degrees of planning and appropriation—can be transformed into non-formal learning environments. While TU Delft reflects an emergent, adaptive strategy, Cornell exemplifies deliberate pedagogical programming. The following sections examine each case in detail, unpacking their spatial logics, institutional histories, and architectural affordances.

4.1 Case Study: Faculty of Architecture, Delft University of Technology

The Faculty of Architecture at Delft University of Technology (TU Delft) holds a distinguished position within the global landscape of architectural education. Recognized for its excellence in design-based pedagogy, the faculty has historically occupied prominent architectural spaces that both reflect and reinforce its academic identity. Since 2009, the faculty has been located in a striking red-brick building on campus which was reappropriated following a catastrophic fire in 2008. The original faculty building was the result of an internal design competition in 1956, won by Van den Broek and Jaap Bakema, who were also the architects of the university's emblematic auditorium. Completed in 1970, the building exemplified the integration of modernist functionalism with educational programming. Constructed primarily in concrete, the structure reflected a clear hierarchy: the lower levels housed shared functions such as the library, administration, canteen, and workshops, while the upper floors were vertically segmented by academic year, with each studio level tailored to the pedagogical needs of specific phases of architectural training. At the spatial core of the building was a central hall, where the low-rise communal base intersected with the vertical studio tower. This hall functioned as a dynamic and flexible meeting ground, promoting visual and spatial continuity. Open to its surroundings and designed to accommodate multiple activities, it served as a key non-formal learning space within the institutional structure.

In May 2008, a fire devastated the original faculty building, prompting an urgent need for relocation. The university decided to renovate a former Faculty of Chemistry building—previously sold to a private developer—and transform it into a new home for the architecture school. This decision mobilized a consortium of architectural firms, including Braaksma & Roos, Fokkema Architects, MVRDV, and others, who collaborated over five years to create a temporarily permanent environment supportive of studio-based education.

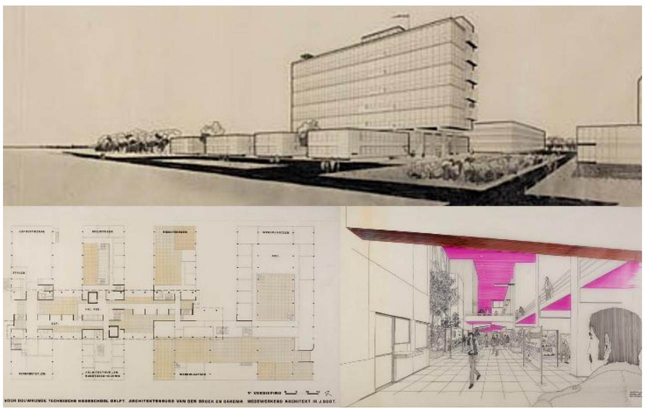

Fig. 1. Drawings of the first Delft TU Faculty of Architecture Building, 1956(NAI, 2008)

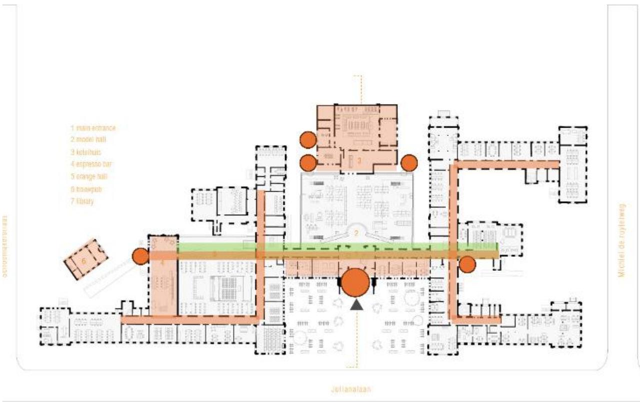

Fig. 2. Relationship analysis of intermediate spaces (Braaksma-Roos, n.d.), Edited by: N. Sezgin

Braaksma & Roos led the architectural coordination, Fokkema oversaw interior design and programming, while Octatube engineered new glazed extensions. The collaborative process emphasized speed, adaptability, and spatial continuity, all of which were essential to restoring the pedagogical rhythm of the school.

A defining element of the adaptive reuse was the incorporation of a "street" concept, inspired by urban morphology. Functioning as the primary circulation spine, this long internal corridor unified various public and semi-public functions, including the print lab, library, café bar, and restaurant, alongside open studios and instructional spaces. The spatial logic echoed that of a city's main thoroughfare, organizing attraction points and enabling spontaneous encounters between students and faculty.

In this configuration, the corridor transcended its role as a mere circulation route and became a social and pedagogical core of the faculty. It connected two enclosed courtyards that acted as internal plazas, further reinforcing the building's role as a site of interaction, appropriation, and informal learning.

4.2 Case Study: Cornell University College of Architecture, Art, and Planning (AAP)

Cornell University AAP is located in the Arts Quad on campus in Ithaca, and consists of Sibley Hall, Rand Hall, and Milstein Hall. These buildings reflect the evolving academic vision of the institution, from 19th century.

Sibley Hall, constructed in three phases between 1870 and 1902, anchors the AAP within the university's central academic zone (*Sibley Hall | Cornell University Veterans Memorials*, n.d.). Adjacent to it, Rand Hall, designed by Gibb & Waltz and completed in 1911, initially served the College of Mechanical Engineering. Over time, it was repurposed as a space for architectural workshops, fabrication labs, and, most recently, the Mui Ho Fine Arts Library, reopened in 2019 following a major renovation. This transformation included the creation of a four-story vertical book stack and a reconfiguration of the ground level into a materials fabrication center housing digital production labs, wood and metal shops, and maker spaces.

In 2001, Cornell launched an invited architectural competition for a new building for the Department of Architecture that would not only meet programmatic expenses but also facilitate a vision of an integrated and integrated architectural education.The shortlisted entries were Steven Holl Architects, Peter Zumthor, Morphosis, and OMA. Though Steven Holl initially won the competition, the project was not realized. (Steven Holl Architects, n.d.)

Fig. 3. Cornell University AAP (Astbury, 2015), Edited by: N. Sezgin

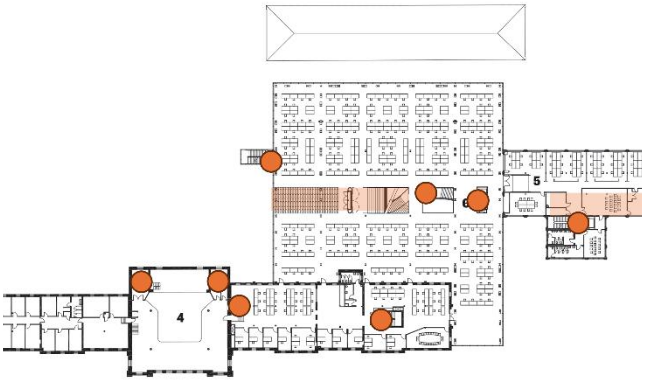

Fig. 4. L.P. Kwee Studios at Milstein Hall (Astbury, 2015), Edited by: N. Sezgin

Completed in 2011, Milstein Hall exemplifies OMA's critical approach to site, history, and program. Rather than demolishing existing structures, OMA inserted Milstein as a mediating volume, weaving together Sibley and Rand Halls without erasing their identities. This act of connection and juxtaposition enabled both architectural contrast and academic continuity.

The building adds approximately 4,400 square meters to the college, with a prominent cantilevered upper level that bridges Sibley and Rand Halls. The second floor houses an expansive studio plate—characterized by a flat, open, and flexible layout—featuring floor-to-ceiling glass façades, 41 skylights, and multiple informal presentation zones centrally embedded within the plan. These areas, equipped with folding partitions and LCD screens, function as non-formal learning environments where peer critique, exhibition, and spontaneous review sessions occur without rigid scheduling.

The studio floor floats above a transparent ground level, supported by slender columns and activated as a circulation and gathering space. This level includes student lounges, gallery zones, and transition areas that operate as thresholds between formal instruction and informal engagement. The architectural articulation of movement—ramping connections, visual transparency, and continuous floor plates—enhances permeability and promotes chance encounters between users from different academic years and disciplines.

Moreover, Milstein's insertion above the University Avenue pedestrian pathway physically and symbolically elevates the architectural program, bridging not only buildings but also ideas and communities. The deliberate visibility of students working inside the glass volume reinforces a culture of openness and learning-as-performance, where the built environment itself becomes an educational medium.

Milstein Hall exemplifies how circulation space can function as pedagogical infrastructure. Rather than relegating movement to the periphery, the project frames circulation as the organizing logic of educational life—a spatial structure that enables collaboration, transition, and reflection. As such, it aligns closely with the theoretical framework discussed earlier, wherein in-between spaces are reimagined as intentional non-formal learning settings. Milstein Hall, in this light, is not merely a connective tissue between historic volumes but a deliberate act of spatial pedagogy—an architectural gesture that embodies the epistemological openness of design education.

4.3 Comparative Spatial Dimensions

The comparative analysis of TU Delft and Cornell AAP reveals distinct spatial strategies that inform how circulation areas are conceptualized and activated as non-formal learning environments. Table 1 outlines six key dimensions. Each reflects varying degrees of design intentionality, user appropriation, and pedagogical alignment.

Table 1. A structured comparison reveals the following key dimensions across both institutions:

Spatial Dimension	TU Delft	Cornell AAP
Circulation as Spine	Central "street" serves as a linear yet permeable connector, linking workshops, cafés, studios.	Cantilevered studio slab bridges buildings; circulation overlaps with programmatic flows.
Visual Transparency	Partial transparency allows glimpses into adjacent spaces, fostering passive observation.	Studio features floor-to-ceiling glazing and skylights, enabling full visual permeability.
Programmatic Integration	Embedded cafés, gallery surfaces, and workshops enhance the corridor's multifunctionality.	Informal review platforms and exhibition areas are directly structured within the studio layout.

Table 1 continued. A structured comparison reveals the following key dimensions across both institutions:

Spatial Dimension	TU Delft	Cornell AAP
Pedagogical Intent	A mix of planned and emergent use; some zones explicitly pedagogical, others appropriated.	High degree of intentionality; non-formal learning is embedded from the outset.
Encounter & Exchange	"Street" encourages unplanned meetings at nodes of overlap; atriums serve as social hubs.	Intersections, visual links, and transitional zones enable peer dialogue and public engagement.
Urban & Campus Interface	Deep integration with the intellectual and spatial identity of Delft's civic fabric.	Milstein bridges historic buildings and the broader campus, symbolizing openness and connection.

4.4 Categorization by Learning Type

The typology of formal, non-formal, and informal learning offers a conceptual lens to evaluate how architectural space supports different modes of education. The examples observed at TU Delft and Cornell AAP reflect a layered spatial ecosystem, where multiple learning modes co-exist, overlap, and transition dynamically.

Table 2. Typology of Use: Formal – Non-formal – Informal

Learning Type	TU Delft Example	Cornell AAP Example
Formal	Studio levels within structured pedagogy; classrooms for theoretical teaching..	Open plan studios and classrooms for theoretical teaching within structured pedagogy.
Non-formal	"Orange Room", model workshop, and integrated display panels along circulation spine.	Informal presentation platforms and basement exhibition spaces embedded in studio fabric.
Informal	Cafés and casual seating spaces; threshold-based interactions.	Comfortable seating spaces and transitional nodes between the new structure and the existing ones.

This triadic framework illustrates a continuum of spatial pedagogies—from rigidly programmed instruction to spontaneous co-learning. Notably, the same space may oscillate between categories depending on use: a gallery wall may support both scheduled critiques and impromptu peer feedback.

By embedding non-formal and informal opportunities into circulation, both schools create learning-rich environments where education is not confined to assigned times and places, but rather enacted across space through presence, interaction, and appropriation.

5. Findings & Comparative Analysis

The spatial case studies of TU Delft and Cornell AAP demonstrate how circulation areas—often conceived as secondary or transitional zones—can be actively engaged as non-formal learning environments when pedagogically reframed or spatially appropriated. While both institutions exhibit design strategies that support learning beyond the classroom, they do so through differing formal expressions, levels of intentionality, and degrees of integration with academic culture.

5.1 Spatial Logic and Pedagogical Intent

At TU Delft, the transformation of the post-fire Red Building into a porous and socially active structure led to the emergence of a central "street," which acts not only as a circulation spine but also as a host of overlapping activities. Some functions—such as the model workshop and Orange Room—were deliberately placed along this spine to support informal review, making, and collaborative work. These zones align with non-formal learning typologies, in which learning is semi-programmed and occurs adjacent to, but outside, the formal curriculum (Colley et al., 2003).

Conversely, at Cornell, Milstein Hall's architectural intent explicitly prioritizes flexible, open-ended learning. The open-plan studio, integrated informal presentation platforms, and exhibition areas reflect an embedded pedagogical strategy to make design learning visible, collective, and situated in space. Circulation here is not simply a means of movement but an architectural act of pedagogical framing (Ellis & Goodyear, 2016).

5.2 Circulation as Pedagogical Infrastructure

In both cases, circulation spaces are not neutral voids but activated volumes. As previously shown in Table 2, these spatial typologies illustrate the spectrum between formal instruction and emergent learning. At TU Delft, the linear corridor facilitates programmed and unprogrammed uses: students move, pause, meet, work, and reflect. The integration of display zones and collaborative working spaces supports a culture of production and feedback.

In Milstein Hall, circulation is vertically layered and programmatically rich. Students encounter each other across multiple axes—visual, spatial, and functional. This complexity encourages inter-year visibility, interdisciplinary exposure, and spatial serendipity. The design strategy aligns with Kuh's call for "seamless learning environments", where spatial transitions support educational continuity (Kuh, 1996). These findings align with Ellis and Goodyear's concept of "relational learning ecologies," where space, interaction, and pedagogy are co-constitutive. In both schools, the boundary between movement and learning is deliberately blurred, allowing circulation to serve as a dynamic infrastructure for informal critique, observation, and reflection.(Ellis & Goodyear, 2016)

5.3 Social Interaction and Encounter Design

Both institutions reveal an architectural emphasis on encounter. TU Delft's "street" functions as a social condenser, integrating academic, administrative, and leisure spaces. Its intersections, visual axes, and spatial adjacencies are designed to support spontaneous exchange.

Milstein Hall leverages its elevated structure and transparency to maximize visibility and proximity. Peer interaction is embedded in the floorplate. The building's design fosters a performative culture of learning, where critique, dialogue, and observation happen in motion—through the space, not around it.

A key distinction lies in the balance between design intent and emergent use. Cornell's configuration stems from a high level of premeditated spatial programming, whereas TU Delft's reuse strategy enabled user-driven adaptation over time. This divergence illustrates two pedagogical paradigms: one that anticipates learning behavior through spatial planning, and one that invites it through open-ended affordances.

Understanding this spectrum is critical to evaluating how spatial agency and pedagogical strategy intersect in design education. Both approaches demonstrate that learning does not solely depend on content delivery, but also on how space enables participation, co-presence, and appropriation.

5.4 Toward Circulation as Pedagogical Infrastructure

Rather than serving as passive backdrops, circulation areas in both cases operate as pedagogically charged terrains. They accommodate formal movement while simultaneously nurturing informal interaction and cognitive extension. Whether shaped through design (Cornell) or shaped by use (TU Delft), these environments demonstrate the potential of circulation to function as infrastructure for deep, distributed learning.

This reconceptualization challenges educators and designers to move beyond the dichotomy of programmed vs. unprogrammed space, and toward a hybrid model that integrates physical flow with epistemic openness.

Circulation in architecture schools is never neutral. It is designed, perceived, negotiated, and inhabited. When intentionally shaped or creatively appropriated, these transitional zones can become pedagogical agents—supporting the informal rhythms, peer-based culture, and spatial freedom that characterize contemporary design education.

6. Discussion

The findings of this study reveal that circulation spaces—traditionally perceived as neutral infrastructural elements—hold substantial potential to function as non-formal learning environments, particularly within schools of architecture where spatial engagement is both the object and medium of education. The comparative cases of TU Delft and Cornell AAP demonstrate that the design, adaptation, and occupation of circulation zones can profoundly influence learning behaviors, peer interaction, and the pedagogical culture of institutions.

6.1 From Threshold to Learning Space: Expanding the Definition

In architectural discourse, in-between and threshold spaces have often been discussed in symbolic or theoretical terms—zones of ambiguity, transition, or resistance (Tschumi, 1996; Wigley, 1991)(Wigley, 1991; Tschumi, 1996). This study extends that discourse by examining how such spaces may evolve into intentional or emergent sites of learning. When circulation areas are spatially open, socially permeable, and programmatically flexible, they become fertile ground for peer exchange, critique, and experimentation—hallmarks of architectural pedagogy.

As Ellis & Goodyear argue, learning environments must be understood not as passive containers but as relational ecologies, where space, people, and pedagogy intersect. The cases analyzed here confirm this view: circulation is not only a backdrop to education but a co-producing agent, mediating between formal and informal, planned and improvised learning encounters. (Ellis & Goodyear, 2016)

6.2 Non-Formal Learning as Spatial Practice

While formal education is structured around defined curricula and time-bound activities, non-formal learning emerges in the interstices—between classes, across studio discussions, in informal reviews, and during spontaneous meetings. The physical support of such learning relies on spatial conditions that afford choice, visibility, adaptability, and comfort.

At TU Delft, the "street" concept illustrates how a retrofitted space, originally not designed for educational purposes, can be appropriated by users to foster a collaborative and iterative culture. At Cornell, OMA's design of Milstein Hall embeds non-formal affordances into the architecture from the outset—platforms, open floors, and visual connections that support spontaneous teaching moments and co-presence.

This comparison highlights an essential duality: non-formal learning can be enabled both through intentional design and emergent occupation. What matters is not only whether a space is designed for learning, but whether it is perceived, inhabited, and transformed as such by its users.

6.3 Pedagogical Implications for Architecture Education

Architecture education is inherently spatial, social, and performative. Its processes depend not only on knowledge transmission but on observation, iteration, and situated dialogue. The spatial environments that support this learning must reflect these dynamics.

Both case studies suggest that circulation zones can operate as pedagogical infrastructure—spaces where informal presentation, critique, and reflection become part of the spatial experience. The presence of non-formal spatial conditions allows students to take ownership of their environment, enabling deeper learning through agency and interaction (Wenger, 1998).

Moreover, when circulation spaces are visually transparent and spatially interconnected, they facilitate a culture of visibility and collective awareness. Students witness others at work, are exposed to different approaches, and internalize architectural thinking not only through instruction but through spatial immersion.

6.4 Rethinking Design Responsibility

The role of the designer—and the institution—in shaping learning conditions must be reconsidered. Circulation spaces are not architectural afterthoughts, but strategic territories that reflect institutional values: openness, trust, collaboration, or control. When conceived as pedagogical infrastructure, these spaces invite designers to think beyond utility and toward spatial pedagogy.

Whether through new construction or adaptive reuse, the challenge is to design circulation not just as movement, but as learning in motion. This requires a shift in mindset—from planning for minimum code compliance to cultivating maximum educational richness.

Ultimately, reimagining circulation as a learning space aligns with wider shifts toward collaborative, inclusive, and responsive education. In architecture—where space is both medium and message—the way students move, pause, and interact is not incidental, but integral to how they learn.

7. Conclusion & Recommendations

This study has explored how circulation spaces in architecture schools can transcend their conventional function as transitional zones and evolve into non-formal learning environments that support collaboration, visibility, and pedagogical fluidity. By comparing two institutionally and architecturally distinct cases—TU Delft Faculty of Architecture and Cornell University's College of Architecture, Art, and Planning (AAP)—the research has shown that learning in architecture occurs not only in formal studio settings, but also within interstitial spaces such as corridors, atriums, foyers, and programmatic thresholds.

At TU Delft, a post-crisis adaptive reuse strategy led to the formation of a layered spatial configuration where spontaneous encounters and informal uses emerged organically along a central "street." At Cornell, the deliberate spatial logic of OMA's Milstein Hall generated a platform in which widespread learning was embedded into the very structure of the circulation system.

These findings reinforce the notion that non-formal learning can be spatially enabled and that architectural design plays a direct role in shaping educational culture. Circulation areas, when designed with openness, flexibility, and social permeability, can promote student agency, foster community, and support the informal transmission of knowledge.

From these observations, several spatial and pedagogical implications can be drawn:

- Circulation should be reframed as spatial opportunity. These areas ought to be treated not as residual voids, but as integral components of the learning ecosystem.
- Design should emphasize visibility and interaction. Spatial strategies such as visual transparency, generous transitions, and embedded programmatic nodes (e.g., seating, pin-up spaces, and exhibition zones) may foster unstructured learning encounters.
- User appropriation should be accommodated. Spaces should allow reinterpretation and adaptation by students and faculty. Flexibility of use encourages ownership and innovation.
- Non-formal learning affordances should be intentionally integrated. Informal review areas, social thresholds, and exhibition zones can be embedded within circulation paths to support layered learning.

- Design intent should be balanced with emergent behavior. Spaces should allow for occupation, personalization, and layered appropriation over time.

Reconceptualizing circulation as a learning space aligns with broader pedagogical shifts toward collaborative, student-centered, and context-responsive education. In architecture, where space is both medium and message, how students move, pause, and interact is not incidental but integral to how they learn.

By linking non-formal education theory with architectural design practice, this paper contributes a conceptual perspective to the discourse on learning environments. Furthermore, it positions circulation as a designable and analyzable typology of learning, offering a valuable foundation for future research in spatial pedagogy within design education.

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Regional economics and relocation: A case study of Gümüşhane

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Abstract. Gümüşhane was founded in the 15th century as a mining town, and was named Gümüşhane later due to its rich silver deposits. The town, where the majority of the people were engaged in mining, preserved this position until the end of 18th century. In the late 18th century, mining activities decreased drastically due to technological insufficiency, and the most of the miners migrated. As Gümüşhane is a very mountainous region and the lack of cultivable land for agriculture made the economy of the town dependent on trade. However, the Trabzon-Erzurum Road didn't pass trought downtown but Harşit Valley which was half hour away. This situation created a local economic crisis for Gümüşhane and inhabitants of the town wanted immediate actions by the authorities to prevent poverty. They send countless petitions to the government which emphasized the road's contribution to the local economy and demanded a change in the route. Their request was rejected; according to the authorities, the slope reaching the town would increase the cost and also would make transportation difficult. After their request was rejected by the government, the inhabitants of Gümüşhane took their own action and started to move to the Harşit Valley towards the road. Even though the government tried to prevent this, the number of people living in Bahçeler, the former summer residence, continued to increase. Finally, only after 1923 the new government decided to move the town center to Harşit Valley and rebuilt a new modern city.

Keywords: Gümüşhane; The Trabzon-Erzurum Road; Regional Economics; Relocation; Mining.

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1. Introduction

Throughout the history, spatial structure of a settlement always walk side by side with trade routes, natural and geographical sources, and technological developments or in another word economics. Economic power, and relations shapes the growth of a town and contributes to it. In the late Ottoman Era, the government started to reconstruction of the Trabzon-Erzurum Road hoping it would contributed to economics on imperial and regional level. However the government's agenda didn't always meet with the locals. While the Ottoman government was focusing in the broader picture, locals were hoping to maintain their livelihoods.

This study aims to show how infrastructure, regional economics, and governmental decisions effect a spatial and demographic structure of a town. In doing so, it offers a microhistorical perspective on locals and their struggles in Gümüşhane in the late 19th century. Through archival documents, and petitions, the study focuses on Gümüşhane's urban transformation during and after the construction of the Trabzon-Erzurum Road.

2. A mining town: the short history of Gümüşhane

Gümüşhane was founded as a mining town under the name of Canca. Altought we don't know the exact date of foundation, the first apperiance of Canca name in a written document dated 1487. According to the this document Canca was a small settlement with rich silver mines in the administration of the district of Torul (BOA, MAD 828). In this period, during the reign of Mehmed II (1451-1481), some non-muslim people, especially the Greeks settled in Canca where they worked as miner and exempt from taxes. These policies also maintained in the 16th century and population of Canca increased overtime (Pamuk, 2016, p. 169).

During the reign of Süleyman I (1520-1566), the name of the settlement was changed into "Eski Canca" and a new settlement named *Karye-i Nefs-i Canca-yı Maden* emerged (BOA, MAD 828). This "Yeni Canca", also established as a mining town, is the old settlement area of the city of Gümüşhane, now known as Süleymaniye Mahallesi (Fig. 1). The name of the town also mentoned as "Nefs-i Kasaba-yı Gümüşhane Nam-ı Diğer Canca". Hence, it can be concluded that the name "Gümüşhane" began to be used as of this date. In 1583, there were 50 Muslim, 478 Greek and 116 Armenian households and 16 Muslim individuals in the region (Bostan, 2002, p. 234).

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It would not be wrong to say that some of this inhabitants lived in Eski Canca and some in Yeni Canca (Gümüşhane).

By the 17th century, it is observed that Eski Canca was abandoned and the settlement completely shifted to Gümüşhane. In 1643, here were 134 Muslim and 569 non-Muslim households in Gümüşhane. Also, 41 soldiers were stationed in the castle of Eski Canca. The mining activities in Eski Canca, on the other hand, have not stopped. According to administrative records, 99 miners were working in Old Canca and 545 miners in Gümüşhane (BOA, MAD 644). Based on this, we can say that Gümüşhane, which was founded as a mining town, maintained this characteristic also in the 17th century. It can be understand that the settlement maintained this mining identity in the 18th century as well, and that the income from the silver and copper shipped to Istanbul helped Gümüşhane to flourish and thus mining became the main source of income for the town (Dolu, 2010).

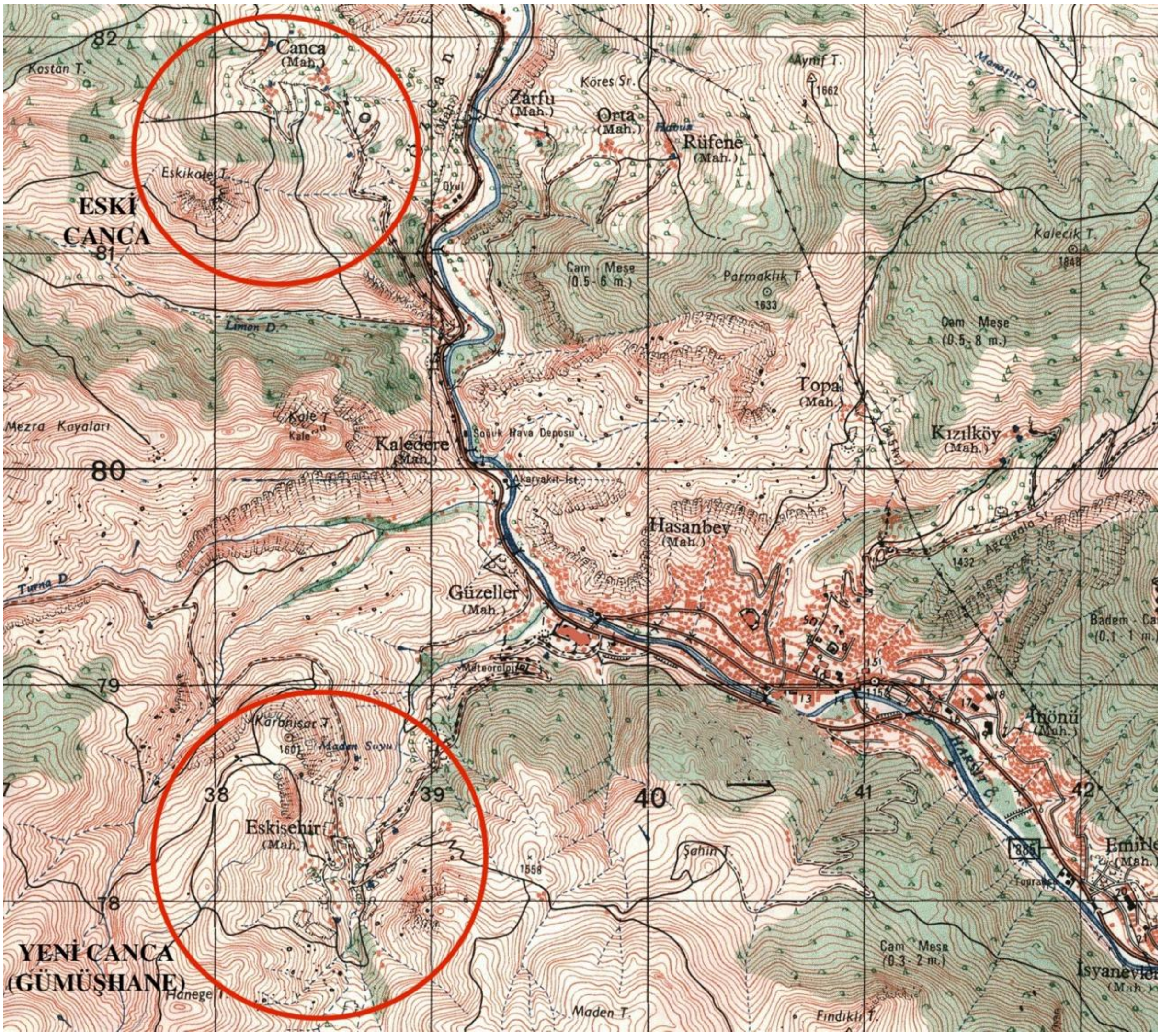

Fig. 1. The settlements of Eski Canca and Yeni Canca (Gümüşhane)

However, by the late 18th century, it is understood that the mining activities in Gümüşhane had paused (TPY, 1870). The mining activities, which were conducted with outdated technological methods, have come to a dead end as a result of this technological inadequacies. The mines have been filled with water and access to the deeper veins has become impossible. Under such circumstances, Gümüşhane, having lost its main source of income, experienced an economic decline and the idea that mining could be replaced by trade seemed a possible solution to cope with these economic circumstances.

3. The reconstruction of the Trabzon-Erzurum Road and the environment led to the relocation

In the beginning of the 19th century, almost 300 years later Ottoman Empire opened Blacksea to the international trade. Thus, Trabzon, one of the port cities of Blacksea, gained a relatively significant importance. This importance led to two significant developments fot the city: new trading possibilities and a visibility in international realm. In a short time Iranian and European merchants began to include Trabzon in their route and the European countries such as England, France, Austria established consulates in the city (Tozlu, 1997).

Following these developments in the Blacksea and with the rising trade potential of Trabzon Port the construction of the Trabzon-Erzurum Road was inevitable. This route started from the port of Trabzon and went to Erzurum through Gümüşhane and Bayburt, and from there to Tabriz via Beyazıd. Therefore, the cities along the route were expected to engage in the commercial activities that would be conducted on this road and profit from them. With these expectations the road works started as an essential government enterprise in 1846 and completed in 1872. However, in 1871, when the road works just started in Gümüşhane region, the trade route did not pass through the town center of Gümüşhane but through Harşit Valley (*Bahçeler*), which is half an hour away (Fig 2). Therefore, the town of Gümüşhane, which was hoping to benefit from the trade, was far away from the road.

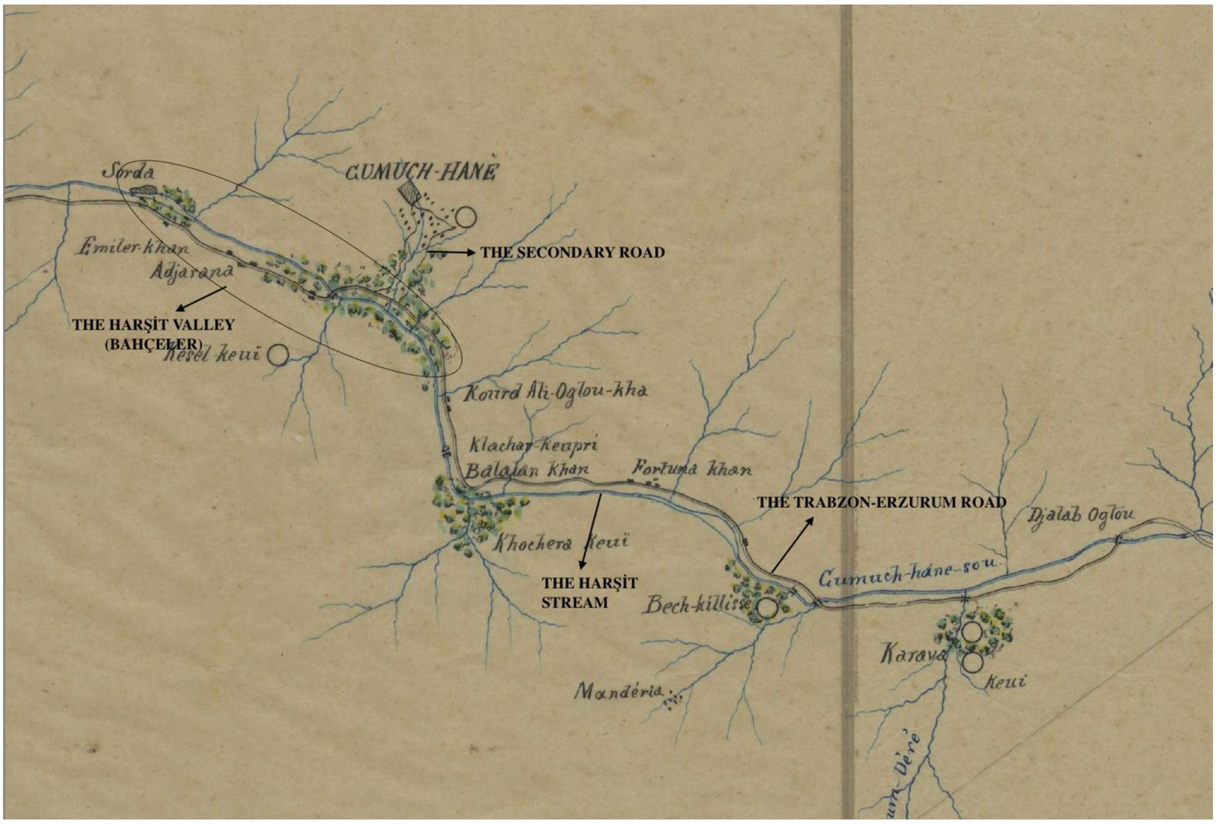

Fig. 2. The Trabzon-Erzurum Road and Gümüşhane town center

The inhabitants of Gümüşhane repeatedly petitioned the Ottoman central government to change the route of the Trabzon-Erzurum road to pass through their town. This was largely because their economy relied heavily on trade, especially after the decline of the silver mines, the main source of income for the town. The first petition sent in 1871, requesting for a route change, which emphasized the contributions to the local economy, was rejected due to the location of town. The justification of the authorities was based on logistical issues such as terrain, construction costs, and the practicality of transporting goods and people (BOA, ŞD 1826/24). The inhabitants sent a second petition in 1873, this time demanding the repair of the secondary road which reach to the town center. We don't have any information how this petition responded, however it is understood from the petitions of the following years that the road was repaired but again was in constant need of repair (BOA, ŞD 1827/49; İ.MMS 78/3421).

Last but not least, in 1892 the inhabitants of Gümüşhane petitioned once more. In this petition, written by a group of 134 people, including leaders of the three religious communities (Muslim, Greek, Armenian), merchants, artisans, craftsmen, tradesmen and locals, the reasons for the route change were clearly presented and asked for a reconsideration. According to the inhabitants, the route change would end the constant repair work that had to be conducted on the secondary road, which would not only reduce costs but also contribute to the local economy. Moreover, the lack of cultivable land in Gümüşhane, a mountainous region, made the economy dependent on trade, and the fact that the mines could no longer be operated increased the importance of trade. In 1883, some attempts were made to operate the silver mines, but failed. All these conflicts piled upon each other and the income of the town declined by 75%. Last bu not least, the miners were migrating to different parts of the empire and the population of the town was decreasing. The inhabitants stated that Gümüşhane was experiencing difficult economic times, that the economic and demographic difficulties would not be reversed unless effective solutions, such as a change in the route, were taken, and that they were disappointed that they had not been able to benefit from the trade road for twenty years, which they had spent a great deal of effort on (BOA, BEO 11/803).

However, all these requests were rejected by the government, which argued that a change of route was not necessary and the extension of the road to the towncenter was also disadvantageous. Without elaborating on the disadvantages, the government noted that even if the route was changed, it would not benefit the town as much as expected because merchants preferred the road through *Bahçeler* rather than climb up to the towncenter (BOA, DH.MKT, 1346/111). In the end, the government never allowed the Trabzon-Erzurum Road to pass through the town center and inhabitants began to look for other solutions to deal with the economic crisis the city was facing.

4. Adapting the new situation: Could relocation possible?

The fact that the trade route was far from the towncenter and the unfavorable conditions of the secondary road forced the inhabitants of the town to search for solutions. The transportation became more challenging, especially during the winter, causing merchants to continue on their way without making a stop in the towncenter, which rendered the inns in there non-functional. As a result, the residents of the town began to leave towncenter and move to *Bahçeler*. We don't know exactly when this relocation process started, but according to the 1877 provincial yearbooks, there were 253 households in the five neighborhoods in *Bahçeler*, which corresponded to 25% of the total population (TPY, 1877). Consequently, the *Bahçeler*, which had previously been used as a recreational area (*mesire*), began to transform into a residential area.

The Ottoman government stated that this attempt was risky for the development of the town and ordered prevention, without elaborating on the details of said risk (BOA, DH.MKT 1130/74). However, this relocation process continued anyway. Moreover, inhabitants of *Bahçeler,* began to ask if the town center could be relocated in Harşit Valley as well. In their opinion, the markets to be established along this road could help revive the town's economy and regain its lost income. It was emphasized that the current town center of Gümüşhane was not sufficient to be a center, and the region was unsuitable for trade and agriculture, regardless of what was done for this location, it would be useless. For this reason, residents suggested that the current center of the Gümüşhane should be moved to the *Bahçeler* region and transformed into a sub-district. They demanded that the police station and telegraph office, schools, the government house and after a while the municipality office should transferred *Bahçeler* as well (BOA, BEO 2242/168091). According to the inhabitants, the relocation of the town to the *Bahçeler* was crucial in many aspects both for the development of the area and preventing depopulation (BOA, DH.MKT 942/49). However, the government rejected all of these requests stating that moving the town to the Harşit Valley, would not benefit the town in the slightest (BOA, DH.MKT 1130/22).

In the early 20th century, the inhabitation in *Bahçeler* continued to rise. In 1907, there were 500 households in Bahçeler and 600 in the town center. Both parts of the town lived in the same time, Gümüşhane (today Süleymaniye) and *Bahçeler* continued to live side by side as parts of a town. The residents of Bahçeler, continued to go town center for work, school or other daily affairs and turn back home in the evening. At the end, the town maintained its current location and the government never allowed a relocation. However, the economic and demographic problems the town was facing remained unsolved.

5. Gümüşhane in the Early Rebublican Era

After WWI, Ottoman Empire collapsed and a new Turkish Republic was founded. This new government aimed to rebuilt the country; whole new economic, education, healt system, and of course new urban plans. Under this new government rule, a new government house for Gümüşhane built in 1922, in *Bahçeler* and we can easily say that this was the first step of the foundation of a new town center. Because, with this step the administrative center of Gümüşhane moved to *Bahçeler* for the first time, and also with this step the decline of Gümüşhane (town center) was started while *Bahçeler* continued to rise. In the first 15 year after the foundation of the republic, a community center (*halkevi*), a modern mosque, an elementary school, a hospital, a middle school, a municipality building, a slaughterhouse, a modern hotel, many fountains for water supply, and 650 houses built in the town (Okay, 1938, pp. 25-28). Also new shops, stores and other commercial building established next to the Trabzon-Erzurum Road (Göktaş, 2020, p. 450).

An important turning point of the development of Gümüşhane province was the foundation of the General Inspectorate III (*III. Umum Müfettişliği*) in 1935 in order to ensure regional development in some provinces of the Eastern Black Sea and Eastern Anatolia. One of the most crucial tasks that General Inspector Tahsin Uzer wanted to accomplish in the area of his inspectorate was the reconstruction of the urban areas. Uzer, therefore, made an intensive effort to transform the inspectorate region, which included Gümüşhane, from its long years of occupation and wars that had turned it into a ruins. In this context, a master plan for the Gümüşhane province was commissioned, and with this new plan *Bahçeler* was designed to be the center of the town and the old town center was transformed into a neighborhood attached to it (Göktaş, 2020, pp. 450-451).

6. Conclusion

This detailed story paints a vivid picture of struggles of Gümüşhane regarding the local economics. The petitions by residents of Gümüşhane reflect the community's desire for economic prosperity, the importance of trade, and a sense of fairness and accessibility. The community's repeated demands for the road to pass through their town center underscore the centrality of infrastructure to economic development, while their frustration at the bypassing of a major trade route highlights how geography and government decisions directly affect local livelihoods. On the other hand, this case shows that how economic problems transforms the urban pattern. The town center of Gümüşhane was forced to relocate by the economic conditions. For a long time, the town existed in two different regions while one part forced to be far away from trading possibilies, the other part to be far away from admimistrative center where the schools and other governmental buildings placed. Finally, in the early republican era its decided to relocate the town in *Bahçeler* and abandoned the historical town center completely. In the end, a historical city turned into a ruined/forgotten neighbourhood and a new town born almost from stracth.

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A review of innovation research in Building Information Modelling (BIM)

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Abstract. The increasing use of Building Information Modeling (BIM) in the Architecture, Engineering, and Construction (AEC) industry, combined with rapid technological progress, has fostered the development of various digital innovations within BIM practices. As the industry undergoes digital transformation, information flows have shifted from human-dependent processes to systems driven by advanced digital tools and platforms. This shift has triggered significant changes in professional roles, collaborative dynamics, operational methods, and stakeholder identities across construction projects. Within this transformation, digital innovation refers to integrating emerging digital technologies, channels, and methodologies that enhance organizational efficiency, service delivery, and building design processes in AEC firms. Technologies central to this innovation include the Internet of Things (IoT), 3D printing, drone applications, sensor integration, augmented and virtual reality (AR/VR), digital twin systems, and cloud-based BIM solutions. This study examines current research on BIM-related innovations, aiming to identify leading technological advancements and trends. The findings contribute to the growing knowledge on BIM innovation and offer insights for researchers and professionals within the AEC industry.

Keywords: Innovation; Building Information Modelling (BIM); Architecture, Engineering and Construction (AEC) industry

1. Introduction

A construction project involves real-world operations unfolding within specific temporal and spatial contexts. Since the progression of time is irreversible and construction environments vary geographically and socially, the participants engaged in these projects are inherently diverse. Consequently, each project is shaped by distinct objectives and constraints. This diversity in individuals, settings, and timelines renders exact replicating construction activities impractical. Every construction endeavor is unique, making innovation a vital element for success (Liu et al., 2020). Factors such as stakeholder complexity, industry fragmentation, and consistently low profit margins and productivity levels underscore the sector's suitability for digital transformation (Morgan, 2019). In an era of digital advancement, there is increasing pressure on the construction sector to deliver higher-quality structures and services more efficiently, within tighter budgets and timeframes. As a result, innovation and performance optimization have become central priorities in the architecture, engineering, and construction (AEC).

Innovation has become a central concept across scientific and technological fields in recent years. It is broadly defined as introducing novel products, services, production techniques, marketing strategies, or organizational structures (Trott, 2005). The innovation process involves multiple stages, including exploration, identification, experimentation, development, and the eventual adaptation or replication of new ideas (Dosi, 1988). At its core, innovation signifies implementing more effective methods for accomplishing specific tasks. It may take various forms, from incremental improvements to transformative or disruptive changes in thinking, processes, products, or organizational frameworks. Fundamentally, it represents generating and applying new knowledge related to ideas, products, or operational approaches. Successful innovations often carry commercial value and contribute to competitive advantage. While innovation is frequently linked to technological advancements, it spans non-technological domains such as organizational and financial systems. It may be realized by introducing new offerings to the market (product innovation) or optimizing internal operations (process innovation). Despite this diversity, all innovation activities aim to boost economic performance and enhance competitiveness.

The literature presents various definitions regarding innovation, some of which are summarized in Table 1. According to Jones and Saad (2003), innovation is composed of two primary components: the internal structure

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of the firm and its capacity to engage with innovation, and the external environment, shaped by technical, economic, social, and institutional dynamics. For a change to qualify as an innovation, it must introduce a new or significantly improved product, process, marketing strategy, or organizational method relative to the firm's existing practices. This can include original developments and adaptations of existing innovations from other organizations (Oslo Manual, 2005).

Innovation also possesses several defining characteristics. One such feature is its irreversibility—once a new technology is adopted, it stimulates further development through user interaction. In contrast, older technologies stagnate due to a lack of active engagement (Jorde and Teece, 1989). Another key aspect is the cumulative nature of innovation. Innovations are often grounded in previous scientific or technological advancements and, in turn, lay the groundwork for subsequent developments. Thus, each innovation contributes to shaping the trajectory of future progress (Teece, 2000).

Table 1. Definitions of innovation in scientific literature

Definition	Source
Introducing entirely new components or novel combinations of existing elements into industrial systems.	Schumpeter, 1934
Encompassing all activities from fundamental research to invention aimed at developing and commercializing new products or production techniques.	Kamien and Schwartz, 1982
Involving the creation of a new product, service, or operational method.	Abernathy and Clark, 1985 Papadonikolaki et al., 2017
A comprehensive process including the exploration, development, adaptation, and market application of novel ideas in processes, products, or organizational systems.	Jorde and Teece, 1992
The effective use of a substantially new or enhanced process, product, or system within an organization.	Slaughter, 1998.
Introducing a novel or substantially enhanced product (either a good or a service), process for production or delivery, marketing method, or organizational practice designed to improve performance or create added value.	Oslo Manual, 2005
The effective realization of novel concepts that result in a measurable economic or market advantage.	Ramilo and Embi, 2014

Innovation is critical in advancing the construction industry (Liu et al., 2020; Li, 2008). The innovation process within this sector often begins in response to client requirements and expectations. Different innovative practices can be observed across various stages, including design, construction, project management, communication, manufacturing, and procurement. In the field of architecture, engineering, and construction (AEC), Oslo Manual (2005) categorized innovation into four distinct types:

- Technological innovation: the application of new knowledge or techniques to deliver products or services more cost-effectively or with enhanced quality;
- Organizational innovation: improvements rooted in changes to social structures, interactions, or cultural dynamics, rather than technological advancements;
- Product innovation: technological developments that may reduce hardware dependency while improving resource efficiency and leading to better-quality outputs;
- Process innovation: modifications to workflows or procedures that yield significant efficiency gains, even in the absence of major technological change.

Construction technologies typically emerge through the integration of diverse technical expertise contributed by various stakeholders, making the innovation process in construction inherently collaborative. Collaboration is a defining characteristic and a fundamental prerequisite for successful innovation in the sector. Nevertheless, this collaborative nature can also introduce significant challenges. According to Xue et al. (2014), one of the primary barriers to achieving the performance improvements needed in construction innovation is the lack of enduring and sustainable cooperation within innovation networks.

Skibniewski and Zavadskas (2013) examined the progression of innovation in the construction industry. They highlighted that the development of the internet and information and communication technologies has opened new and promising avenues for innovation in this field. As the construction industry undergoes digital transformation, Building Information Modeling (BIM) has become a central approach driving technological change across the sector (Papadonikolaki et al., 2019).

Initially conceptualized by Eastman in the 1970s, BIM has evolved into a comprehensive process that spans the entire life cycle of a project, from design through to operation. Despite the variety of definitions available in the literature, a common understanding is that BIM serves as a digital platform that integrates both the physical and functional attributes of a building. For instance, the National BIM Standard – United States (2010) describes

BIM as a digital representation of a facility's characteristics. Similarly, the Associated General Contractors of America (2005) defines it as using software tools to digitally simulate construction and management processes.

The resulting BIM models are typically rich in data, parametric, and composed of intelligent, object-oriented components. According to Laiserin (2002), BIM can be seen as a three-dimensional, object-oriented, computer-aided design framework tailored to the needs of architects, engineers, and contractors. Expanding on this, Hardin (2009) emphasized that BIM represents more than just 3D modeling—it also reflects fundamental innovations in workflow and project delivery methods. Succar et al. (2012) characterized BIM as an integrated framework of policies, procedures, and technologies designed to manage project data digitally throughout a building's lifecycle. Azhar et al. (2012), meanwhile, dissected the concept itself: "building" encompasses all types of projects, "information" refers to spatial, physical, and financial data, and "modeling" denotes the digital simulation of a project's physical components.

Collaboration and innovation are recurring themes in Building Information Modeling (BIM) research, as highlighted by He et al. (2017). While BIM is frequently classified as a technological innovation, it is increasingly recognized as a strategic enabler that fuels broader innovation within the construction sector (Holmström et al., 2015). As construction projects grow in complexity, the demand for innovative approaches to address dynamic and intricate engineering challenges becomes more urgent. BIM serves not only as an innovation but also as a tool for process integration, facilitating other innovations by establishing the necessary communication and social frameworks for transformation. BIM is evolving into a foundational digital infrastructure that supports innovation across the lifecycle of construction projects (Holmström et al., 2015; Morgan, 2019). Its implementation can drive both technological and organizational innovations, and it can potentially enable radical change within the industry (Morgan, 2019).

The widespread adoption of BIM in the architecture, engineering, and construction (AEC) industry, combined with rapid technological advancement, has given rise to various digital innovations. These include integrating technologies such as the Internet of Things (IoT), 3D printing, drones, sensors, augmented and virtual reality, digital twins, and cloud-based BIM (Cloud-BIM), all of which are transforming the way construction projects are designed, managed, and executed.This paper reviews research discussing innovations in BIM. The study aims to identify prominent BIM innovations in the AEC sector. The study contributes to a better understanding of innovation for future research in BIM literature and provides insights to BIM practitioners in the AEC sector.

2. Materials and methods

According to the literature, there are three main approaches to conducting review studies: traditional (or narrative) reviews, systematic reviews, and meta-analyses (Moule & Goodman, 2009; Gerrish & Lacey, 2010). A systematic review is characterized by a structured and comprehensive analysis of all relevant published studies within a specific research domain. This approach involves applying explicit inclusion and exclusion criteria, assessing the quality of the identified studies, and synthesizing their findings to address a particular research question or problem (Higgins & Green, 2011). Systematic reviews may incorporate quantitative, qualitative, or a combination of both types of evidence, referred to as a mixed methods systematic review (Hemingway & Brereton, 2009). These reviews are particularly valuable due to their methodological rigor and ability to generate high levels of evidence.

This study conducted a systematic review to analyze research on innovation within the construction sector's context of Building Information Modeling (BIM). The Scopus database was used as the primary data source. The search was performed using the keywords "BIM", "innovation", and "construction". An initial pool of 1,183 publications was identified.

To refine the dataset, filters were applied to limit the subject area to Engineering and the document type to Article, resulting in 323 relevant records. Further screening was conducted based on specific exclusion criteria:

- 25 articles were excluded because they were not written in English.
- 16 articles published in 2025 were removed, as the year was still in progress at the time of analysis, potentially leading to misleading trends in temporal data visualization.
- 1 article dated before 2010 was excluded due to being outside the scope of the study.
- 228 BIM-related articles were excluded because they did not explicitly focus on innovation.

After applying these criteria, 53 articles published between 2010 and 2024 that specifically addressed innovation in the context of BIM were included in the final review. Fig. 1 illustrates the workflow of the systematic literature review, and the findings are presented in the subsequent section.

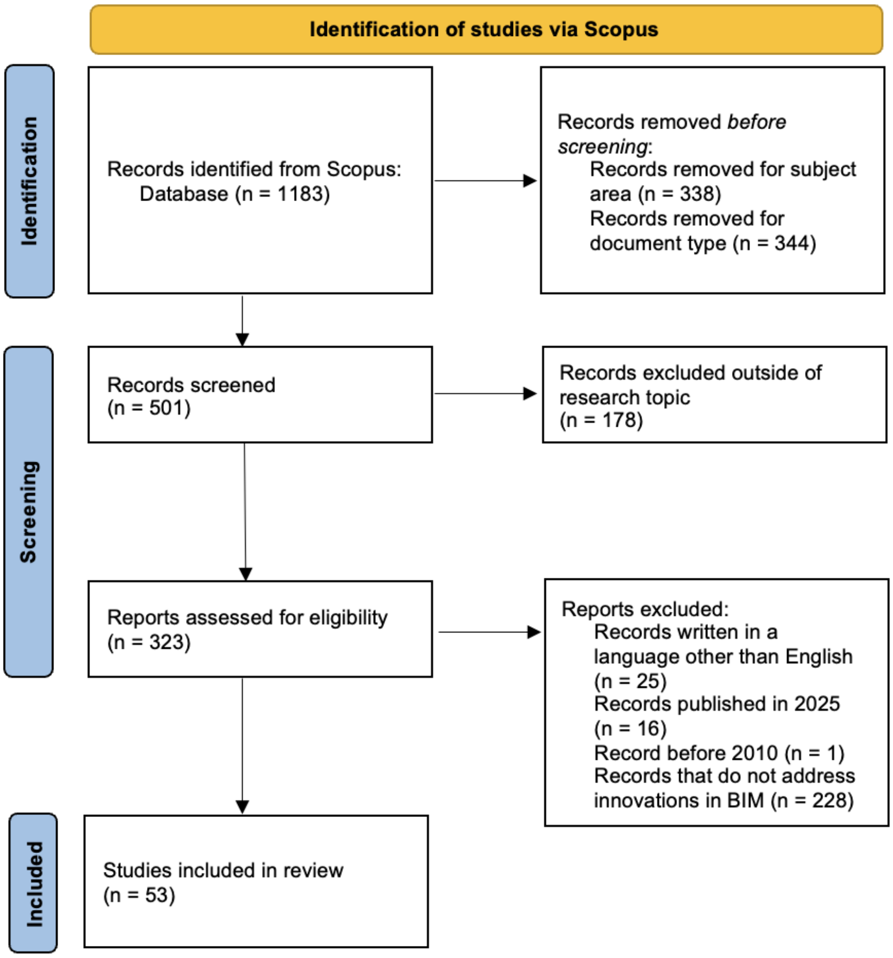

Fig. 1. Framework of the study

3. Results and discussion

In the Scopus database, the distribution of studies addressing innovations in BIM in the Engineering subject area by year is presented in Fig. 2. The first studies on the subject in the literature were published in 2010. Studies addressing innovations in BIM continue to increase each year compared to the previous year. As a result of the systematic literature review, the journals in which 281 articles were published between 2010 and 2024 are presented in Fig. 3. Accordingly, Architectural Engineering and Design Management, Construction Innovation, Engineering Construction and Architectural Management, Automation in Construction, and Buildings were the journals in which the articles within the scope of the subject were published most frequently. When the countries where the research was conducted were considered, most studies were conducted in the United Kingdom, while the fewest studies were conducted in Germany (Fig. 4). When the subject areas of the 281 studies published between 2010 and 2024 were examined, most studies were conducted in the subject area of Engineering, with 51.5%. This was followed by Business, Management, and Accounting with 15.8% and Computer Science with 9.7% (Fig. 5).

As a result of the systematic literature review, 228 out of 281 studies were excluded because they did not focus on a specific innovation in BIM, their subject area was outside the construction industry, or they addressed BIM software as an innovation. The remaining 53 articles were examined in detail within the scope of this research, and the journals in which these studies were published are presented in Table 2. When the journals in which the articles are published are examined, the highest number of publications is in the Buildings journal, with eight articles. This is followed by the Automation in Construction journal with four articles (Table 2).

The innovations discussed in the articles examined within the study's scope were categorized into seven main groups: ND BIM, automation, sustainability, collaboration, management, new model/approach/framework, and technology (Fig. 6).

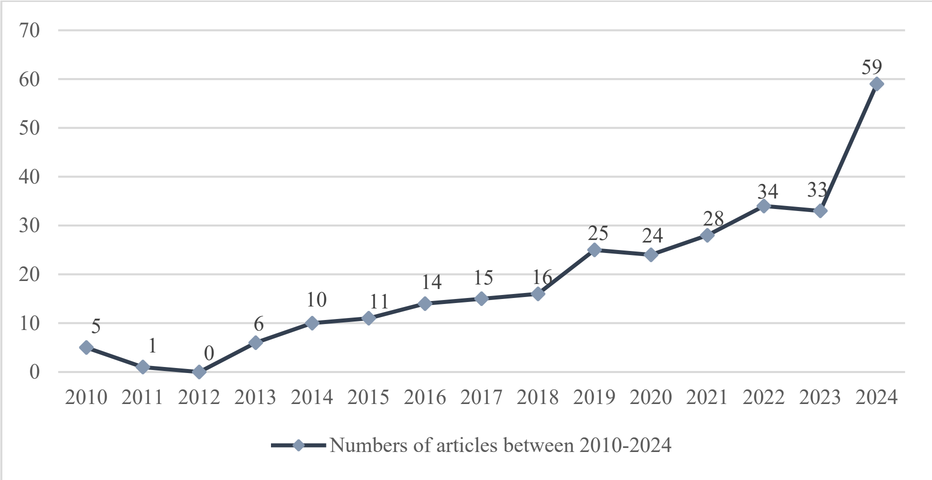

Fig. 2. Distribution of published articles according to years between 2010 and 2024

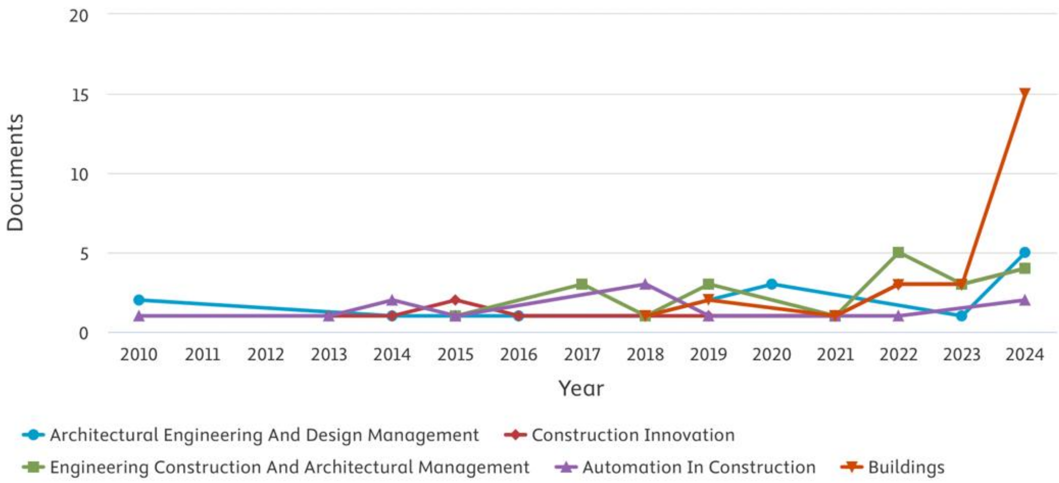

Fig. 3. Documents by year by source

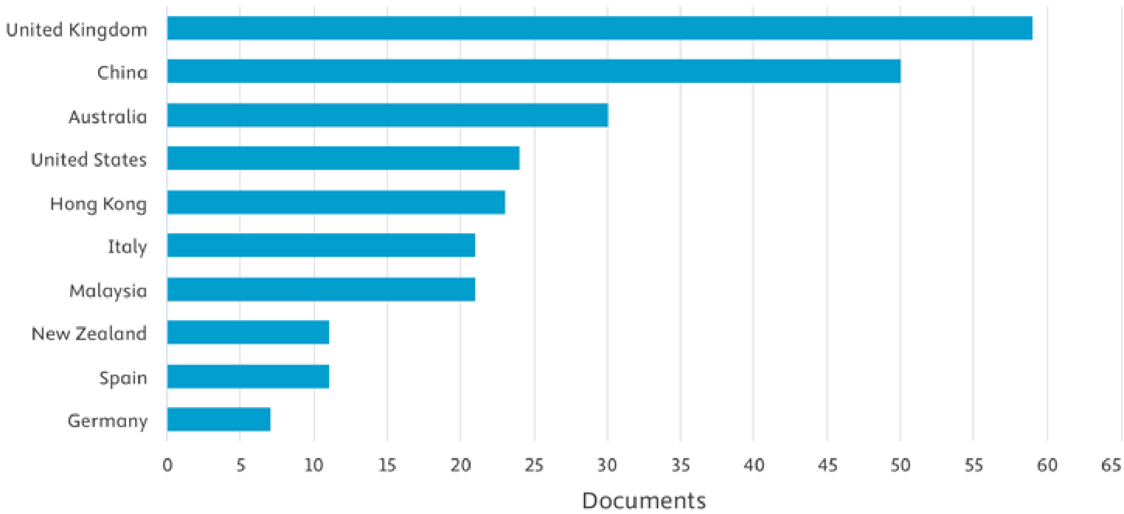

Fig. 4. Documents by country or territory

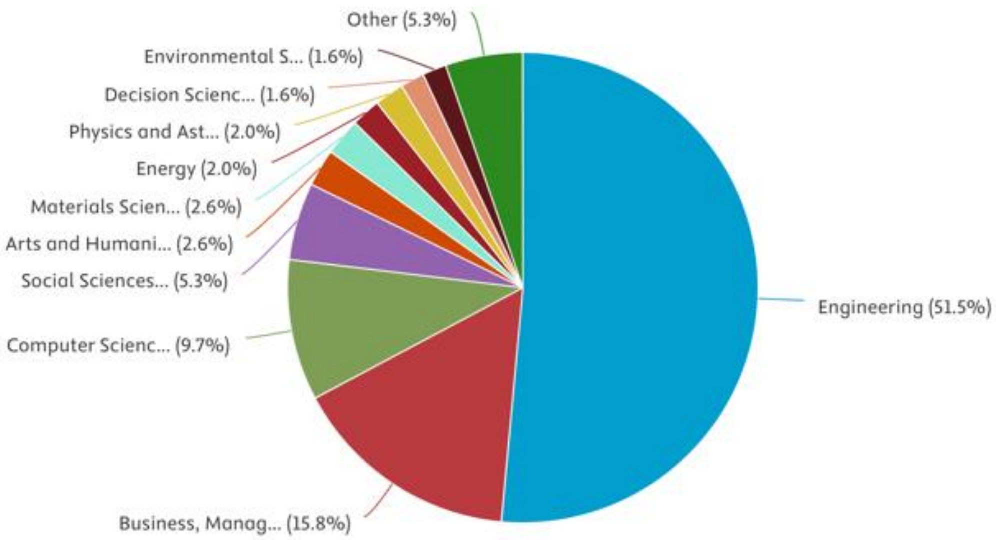

Fig. 5. Documents by subject area

Table 2. Distribution of articles according to the published journal

Journal	Distribution	Source
Acta Imeko	1	Malagnino et al., 2018.
Archives of Civil Engineering	1	Araszkiewicz, 2016.
International Journal of Emerging Trends in Engineering Research	1	Fong Piew, AbdFatah, and Kaidi, 2020.
International Journal of Project Management	1	Papadonikolaki, Oel, and Kagioglou, 2019.
Research Journal of Applied Sciences, Engineering and Technology	1	Umar et al., 2015.
Sensors	1	Zhao, Liu and Mbachu, 2019.
Transportation Research	1	Love et al., 2017.
CivilEng	1	Samsami, 2024.
Project Management Journal	1	Whyte, 2019.
Industrial Management and Data Systems	1	Papadonikolaki et al., 2023.
Journal of Construction, Engineering and Management	1	Brosque, Skeie and Fischer, 2021.
Journal of Cleaner Production	1	Li et al., 2021.
Journal of Building Engineering	1	Yang, de Vries and van der Schaft, 2020.
International Journal of Sustainable Development and Planning	2	Alazmeh, Underwood, and Coates, 2018. Saleeb, Marzouk and Atteya, 2018.
Renewable and Sustainable Energy Reviews	1	Eleftheriadis, Mumovic, and Greening, 2017.
Journal of Information Technology in Construction	2	Ramaji and Memari, 2020. Abbasnejad et al., 2021.
Construction Economics and Building	1	Datta, Ninan and Sankaran, 2020.
Periodica Polytechnica Civil Engineering	1	Bongiorno et al., 2019.
Civil Engineering Dimension	1	Narindri, Nugroho and Aminullah, 2022.
Results in Engineering	1	Musarat et al., 2024.
Designs	1	Baraibar et al., 2022.
Energies	1	Battisti, Persiani and Crespi, 2019.
Sustainable Development	1	Olawumi and Chan, 2019.
Revista de la Construcción	1	Arriagada, 2019.
Sustainability	2	Kaewunruen, Sresakoolchai, and Zhou, 2020. Yang, Zhang, and Xie (2020)

Table 2. Continued

Advances in Civil Engineering	2	Tang et al., 2019. Peng et al., 2020.
Proceedings of the Institution of Civil Engineers: Structures and Buildings	2	Aslam and Umar, 2023. Zhang, Broyd, and Ma, 2023.
Applied Sciences (Switzerland)	2	Mohammed et al., 2022. Sampaio, Constantino and Almeida, 2022.
Automation in Construction	4	McGlinn et al., 2017. Vignali et al., 2021. Tao et al., 2022. Hadavi and Alizadehsalehi, 2024.
Buildings	8	Elagiry et al., 2019. Khattra, Rai, and Singh, 2022. Amici et al., 2022. Gu et al., 2023. Zhang et al., 2023. Shen, 2024. Khan et al., 2024. Choi, Na, and Heo, 2024.
Engineering, Construction and Architectural Management	2	Gledson and Greenwood, 2017. Rashed and Mutis, 2023.
Architectural Engineering and Design Management	1	Ng, Graser and Hall, 2023.
Construction Innovation	2	Abrishami et al., 2015. Georgiadou, 2019.
Construction Management and Economics	2	Papadonikolaki, Verbraeck and Wamelink, 2017. Aksenova et al., 2019.
Total:	53	

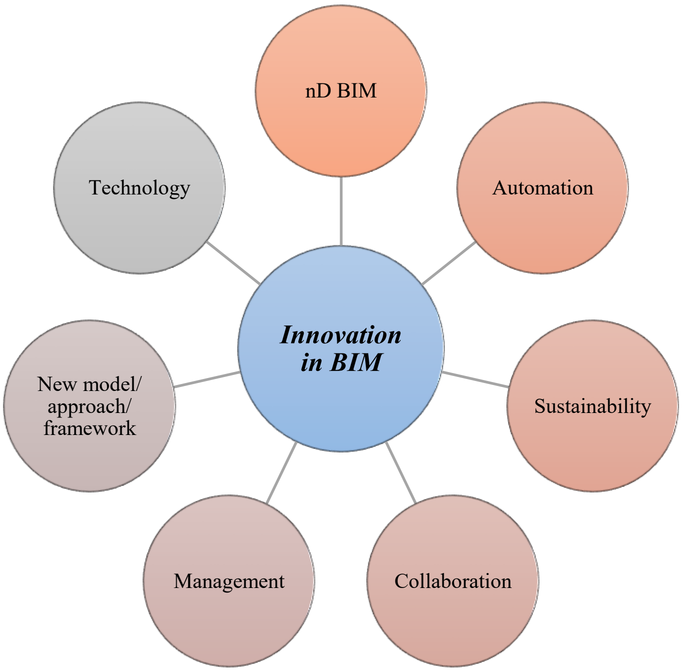

Fig. 6. Categories of innovations in BIM literature

nD BIM: The nD of the BIM development process covers five dimensions. These can be listed as 1D (Planning and Research), 2D (Drawing including plan, section, elevation and project documentation), 3D (Visual representation of the physical structure), 4D (Time planning showing the project schedule), 5D (Cost estimate including material and labor expenses), 6D (Sustainability and life cycle analysis), 7D (Facility management and post-construction data) and 8D (Safety). Umar et al. (2015) stated that project activities can be visually presented with 4D modeling. They examined the impact of 4D applications on Integrated Project Delivery (IPD) in the AEC sector and suggested a strategy for optimizing the tools used in project delivery. Love et al. (2017) discussed the main reasons for cost increases in railway projects and the methods suggested to prevent these increases. They presented that the 5D dimension of BIM can reduce cost uncertainties and increase the probability of completing projects within budget.

Automation: It refers to using automated processes and tools in the BIM platform in construction and architecture to improve various aspects of the project life cycle. Abrishani et al. (2015) discuss the combination of BIM and generative design for an innovative and integrated process management in the early design stages. This research proposes a generative BIM (G-BIM) workspace to overcome the limitations of traditional design processes and develop more effective, flexible, and creative solutions in the early design stages of AEC projects. This environment aims to enable designers to generate alternative solutions through parameters and manage the design process more dynamically. Brosque, Skeie, and Fischer (2021) examine the effectiveness of robotic technology in concrete drilling operations in the construction industry. The study is critical because it presents a detailed analysis of a concrete drilling robot used in the field for the first time. A framework is proposed to compare robotic and traditional construction methods. The study emphasizes the potential of robotic technology in the construction industry and the importance of BIM integration. Baraibar et al. (2022) described the innovative methods used in constructing the Arnotegi Tunnel on the Bilbao Southern Ring Road and their impact on safety, efficiency, and environmental sustainability. To minimize environmental impacts during tunnel construction, parameters such as air quality, noise, and vibration were monitored using various environmental sensors. The machines' positions in the tunnel were precisely determined through 3D digital models and sensors, thus making work processes more efficient.

Collaboration: The BIM collaboration process involves defining different construction phases for a single project. In other words, it consists of understanding the data and information sharing process between different construction phases. Alazmeh et al. (2018) aimed to transform traditional workflows into a BIM-based, collaborative model within a Knowledge Exchange Partnership framework with the University of Salford. The article highlights that BIM has the potential to transform traditional processes in the construction industry and that adopting a collaborative approach can increase the efficiency of projects. Technology development has also pushed the understanding of collaboration in construction projects to change. Gu et al. (2023) examine the social impact of the award-winning U City project in Adelaide, Australia. This research aims to understand the effectiveness of digital collaboration in complex housing projects and stakeholders' perceptions of this process. The research suggests five strategies to increase the effectiveness of digital collaboration in complex housing projects.

Sustainability: Sustainable design can be defined as the purposeful design of buildings and places that minimize harmful environmental impacts, significantly reduce carbon emissions, and positively enhance health, well-being, nature and biodiversity, and social value throughout their life cycle. BIM supports Environmental, Social, and Governance goals by tracking environmental impacts, promoting sustainable resource management, and ensuring transparency and compliance in construction and operations. Zhang et al. (2023) examined the effects of Building Information Modeling (BIM) applications on the sustainability performance of construction projects. The researchers stated that BIM applications increase sustainability performance by encouraging green innovations. Green innovations improve areas such as energy efficiency, waste management, and the use of environmentally friendly materials. The study emphasizes that this process strengthens the impact of BIM on sustainability. Araszkiewicz (2016) discusses the "Green BIM" management method, which combines the concepts of sustainable construction and building information modeling (BIM). The researcher defines the Green BIM concept as an approach that aims to perform energy efficiency, material optimization, and environmental impact assessments in a digital environment by integrating BIM technologies with environmental sustainability goals. The findings of the study;

- Strong institutional support and leadership are required to implement Green BIM effectively.
- Training programs on Green BIM should be organized for engineers and designers, and digital skills should be increased.
- Government policies should encourage sustainable construction practices and ensure the widespread use of Green BIM.

Management: It can be explained as overseeing and coordinating all aspects of a construction project using BIM technology. It enables the efficient management of large amounts of data and information generated during a construction project's planning, design, construction, and operation phases. Ng et al. (2023) examine how digital manufacturing (DFAB), Building Information Modeling (BIM), and Early Commitment Participation (ECI) applications are integrated in construction projects and the effects of this integration on design processes. The study analyzes the effects of these three applications on process integration, information integration, and organizational integration by comparing four different projects.

New model/approach/framework: It defines new models, approaches, or frameworks that have emerged through scientific studies addressing the use of BIM in the construction industry. Khattra et al. (2022) researchers have digitized the design process of structures using the Industry Foundation Classes (IFC) data model, which is the core component of BIM. IFC facilitates data sharing between different software, increasing the accuracy and efficiency of design. The proposed system provides a framework that automatically checks structural elements' design for compliance with a particular country's building codes (e.g., India's IS 13920 seismic code). This reduces human errors in the design process and increases accuracy. This study significantly contributes to automating structural design and ensuring code compliance using a BIM and IFC-based framework. It constitutes a valuable example for increasing digitalization in the construction sector and improving design processes, especially in developing countries.

Technology: Technology in the construction industry is a collection of various tools, applications, software, and machines used in different phases of a construction project. These tools and machines help increase the efficiency of its methods and processes. Peng et al. (2020) examine a digital twin-based building management system implemented in the East Hospital in Shanghai, China. This system is built by continuously integrating static and dynamic data throughout the entire life cycle of the hospital building (design, construction, operation, and maintenance). It includes real-time visual management and AI-assisted diagnostic modules. In addition, Li et al. (2021) propose an innovative digital platform to increase the sustainability of prefabricated housing construction (PHC). This platform aims to make PHC processes more efficient, transparent, and sustainable by integrating advanced information and communication technologies (ICT) such as blockchain, Internet of Things (IoT), Cyber-Physical Systems (CPS), and Building Information Modeling (BIM). Khan et al (2024) evaluate the applicability of 3D printing technology in residential construction in New Zealand regarding environmental sustainability and energy efficiency. The study shows that 3D printing technology can enhance environmental sustainability in New Zealand residential construction. In their study conducted in 2024, Choi et al. (2024) investigated the potential of integrating drone imagery and artificial intelligence (AI) to digitize construction site management. The research aims to create point cloud models (PCM) using drones instead of traditional robots and scanner-based data collection methods, and improve object recognition algorithms by rendering these models photorealistically.

Table 3. Innovations in BIM

Innovation		Source
nD BIM	4D	Umar et al. (2015)
		Gledson and Greenwood (2017)
		Datta, Ninan and Sankaran (2020)
	5D	Love et al. (2017)
	6D	Kaewunruen, Sresakoolchai, and Zhou (2020)
	8D	Sampaio, Constantino and Almeida (2022)
Automation	Automation	Abrishami et al. (2015)
		Ramaji and Memari (2020)
	Robotic	Brosque, Skeie and Fischer (2021)
	Sensors	Baraibar et al. (2022)
		Musarat et al. (2024)
	Code compliance	Aslam and Umar (2023)
	Compliance checking	Zhang, Broyd, and Ma (2023)
Collaboration	Collaboration	Alazmeh, Underwood, and Coates (2018)
		Papadonikolaki, Oel, and Kagioglou (2019)
		Tang et al. (2019)
	Digital collaboration	Gu et al. (2023)
	Integrated project delivery	Rashed and Mutis (2023)
Sustainability	Green BIM	Araszkiewicz (2016)
	BIM-based life cycle	Eleftheriadis, Mumovic, and Greening (2017)
		Ricardo and Arriagada (2019)
		Battisti, Persiani and Crespi (2019)
	Energy Simulation	McGlinn et al. (2017)
	BIM ecosystem	Aksenova et al. (2019)
		Whyte (2019)
		Yang, Zhang, and Xie (2020)
	BIM on site	Yang, Vries and Schaft (2020)
	Green innovation	Zhang et al. (2023)

Table 3. Continued

Management	Business Process Management (BPM) with BIM	Malagnino et al. (2018)
	Classification Systems	Saleeb, Marzouk and Atteya (2018)
	Management of digital information	Georgiadou (2019)
	Business sustainability	Fong Piew, AbdFatah and Kaidi (2020)
	Digital fabrication	Ng, Graser and Hall (2023)
New model/approaches/ framework	BIM4REN	Elagiry et al. (2019)
	Interpretive Structural Modeling (ISM) approach	Abbasnejad et al. (2021)
	IFC-based interoperability framework	Khattra, Rai, and Singh (2022)
	Confidentiality-Minded framework (CMF) for blockchain-based design collaboration	Tao et al. (2022)
	BIM-GIS	Narindri, Nugroho, and Aminullah (2022)
	Model Smart Management framework	Amici et al. (2022)
	BIM-PIMF model	Olawumi and Chan (2019)
Technology	Integration with software	Papadonikolaki, Verbraeck, and Wamelink (2017)
	Cloud-based BIM	Zhao, Liu and Mbachu (2019)
	I-BIM	Bongiorno et al. (2019) Vignali et al. (2021)
	Deep learning algorithms	Akinosho et al. (2020)
	Digital twin	Peng et al. (2020)
	Blockchain	Li et al. (2021)
	Blockchain innovation ecosystem	Papadonikolaki et al. (2023)
	Internet of Things (IoT)	Li et al. (2021) Mohammed et al. (2022)
	Generative AI	Samsami (2024)
	ROCOS (Robot Collaboration System)	Shen (2024)
	3D printing	Khan et al. (2024)
	Drone	Choi, Na, and Heo (2024)
	BIM to Metaverse	Hadavi and Alizadehsalehi (2024)

4. Conclusions

This study reviewed the academic literature to identify key innovations in BIM, focusing on the Architecture, Engineering, and Construction (AEC) Industry. The analysis was based on publications indexed in the Scopus database, covering 2010 to 2024.

The findings indicate that early studies from 2015 primarily explored BIM's foundational aspects and potential to transform traditional construction practices. BIM's innovative capabilities are increasingly emphasized in the literature, particularly in supporting digital transformation and improving project performance. With the advancement of technology, BIM-related innovations have increasingly focused on enabling automation within the construction industry. Integrating emerging tools such as sensors, 3D printers, robots, and drones into construction workflows has significantly enhanced operational efficiency. One of BIM's most notable contributions is its ability to facilitate storing and exchanging extensive data among stakeholders during the project process. This has heightened the importance of process management and handling data generated at various project stages. Various BIM-based management frameworks have been proposed to optimize project execution. Furthermore, recent studies have increasingly addressed the challenges and strategies for managing data stored and processed on digital platforms.

As a result, BIM has become increasingly integrated with digital innovations, leading to the development of new models, approaches, and frameworks in the literature. Recent Internet of Things (IoT) and interoperability studies have introduced concepts like digital twin, blockchain, cloud-based BIM, and Intelligent BIM (I-BIM). Finally, while there has been a growing interest in digital twins, blockchain, and I-BIM, further research could examine the practical challenges and opportunities in implementing these technologies in real-world construction projects.

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The use of artificial intelligence technology in the field of architecture: Current situation and future projections

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Abstract. The concept of artificial intelligence, which emerged in the 1950s with Alan Turing's question, "Can machines think?" is a research field that has evolved to enable machines to perform cognitive skills unique to humans. While early applications were limited to algorithms with small capacities and processing small datasets, today's generative AI technologies have transformed into systems capable of designing new and original content. Thanks to these qualities, generative AI has become applicable in various fields of business, from healthcare to tourism and art education. One of these fields is architecture. Technological advancements have significantly impacted architectural design and implementation, making using artificial intelligence in architecture inevitable.
The impact of artificial intelligence on architecture became apparent with the emergence of parametric design in the late 20th century. Parametric design software, one of the earliest applications of AI in architecture, revolutionized the process of managing geometric complexity and expanded its role in architecture over time. In this context, the research aims to examine the innovations and transformations that artificial intelligence has brought to the field of architecture and to evaluate its potential future impacts. By adopting a narrative approach to reviewing the literature, the study synthesizes views from existing literature to provide a multifaceted and innovative perspective. Particular attention is paid to how generative AI can offer solutions for energy efficiency, material optimization, early detection of potential structural errors, and sustainability. Furthermore, the study explores recommendations for interdisciplinary collaborations, particularly between architecture and fields like computer science, civil, mechanical, and electrical-electronics engineering, to produce more creative, efficient, and environmentally friendly projects.

Keywords: Architecture, Artificial Intelligence, AI, Generative AI, Design, Technology, Sustainability, Interdisciplinary Collaboration

1. Introduction

Architecture is an ancient profession whose roots go deep into human history. Over time, the essence of architecture has been interpreted from different perspectives, and various definitions have emerged. The theoretical framework of this art, which has been practiced for centuries, has been shaped after its practical development. The fact that it has been influenced by social and cultural movements in every period has brought about the expression of architecture in rich, detailed, and literary expressions. According to Vitrivius (2017), architecture is a combination of aesthetics, durability, and functionality. Alberti (1485) considers architecture as an art that exists to enhance human dignity and the welfare of society. Le Corbusier (2007) describes the house as the living machine of modern man and architecture as the design and organization of this machine. The philosopher Heidegger (1999) argues that space is a fundamental dimension of human existence and considers architecture as an expression of this existence. Zaha Hadid (2009) states that architecture should have a content that excites, calms and makes people think beyond form and function. As can be understood from these different perspectives, architecture, which is a complex discipline, provides people with environments in which to live, work, and have fun. Thus, human life is in constant contact with architecture. It is possible to define architecture, which does not have a single correct formula and strict boundaries (Ching & Eckler, 2024), in its simplest form as "*a discipline that regulates the relationship between man and space and makes this relationship meaningful*."

Architectural design is a complex discipline that involves solving many problems by bringing together information from different fields of expertise. Although the main goal is to produce aesthetic, applicable, and ideal solutions in the design process, the data density and problems to be handled are relatively high. This situation causes architects to need more efficient and effective methods in their design processes. Today, digital technologies

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alleviate this intensity and improve design and production processes. Using such technologies in architecture has created new communication between the computer and the designer and a turning point in design processes. Especially in recent years, the increasing use of artificial intelligence (AI) in architecture has radically transformed this field (Chaillou, 2020). AI tools are no longer just for automation; they actively participate in the design process and work with architects. In this way, architects benefit from the analysis and suggestions of AI while producing innovative and creative solutions. In this context, AI is positioned as a tool and a creative partner in architecture, reshaping design processes.

The concept of AI began to take shape as a scientific discipline in the 1950s with Alan Turing's question, "Can machines think?" and has developed rapidly since then. AI is a branch of technology that aims to enable computer systems to demonstrate human-like thinking, learning, problem-solving, and decision-making abilities (Pirim, 2006). AI uses disciplines such as mathematics, computer science, linguistics, psychology, and neuroscience to model human intelligence and develop systems that mimic it (Pirim, 2006). This interdisciplinary collaboration has taken AI to a more advanced level, both technically and theoretically, and has made this technology one of today's most effective and remarkable fields. So much so that AI-supported software developed to fulfill specific tasks outperforms them over time thanks to the experience gained from their users (Arney, 2017). AI technology is not only a technical innovation but also can potentially create a significant change in social and economic spheres. Indeed, AI expert Kai-Fu Lee emphasizes the importance of this transformation, stating that this technology can potentially create a greater impact than any other innovation in human history (Lee & Qiufan, 2021). This has made AI one of the fastest-advancing and most remarkable research fields of recent years (Norvig & Russell, 2016). The expanding application areas of AI are also a remarkable discussion topic for the architecture discipline, which focuses on design and creativity.

The innovations brought by AI technology to the discipline of architecture and its potential to transform the profession is a technological advance and a process that redefines the future of the field. This process, which brings various positive and negative effects, needs to be handled with a critical perspective based on scientific knowledge. Thus, AI can be a powerful tool and a creative partner in building the architecture of the future while preserving the fundamental values of architecture. Structured with this perspective, the study examines the effects of AI on architecture and discusses the current and future uses of this technology from a multidimensional perspective. The study aims to synthesize the existing information from different disciplines in the literature. In this context, the research seeks answers to the following questions within the framework of the fundamental problem: "*What are the current and predicted effects of AI technologies on the discipline of architecture?*":

1. For what purposes are today's AI technologies used in architecture?
2. What are the current and potential risks of AI for the discipline of architecture?
3. What are the prominent study trends and gaps in the literature on the subject?
4. What kind of transformations is AI expected to bring about in architecture in theory and practice?

2. Research Methodology

This study was conducted using the traditional literature review method. A traditional literature review is a method that synthesizes the existing knowledge on the subject, allowing the presentation of a detailed analysis of the basic concepts, development processes, and new approaches related to the field (Paul & Criado, 2020). The research process consists of three stages. In the first stage, academic databases were searched to create a theoretical framework, identify trends and gaps in the literature, and synthesize existing scientific knowledge. Using the keywords "artificial intelligence," "AI," "generative artificial intelligence," "Generative AI, "machine learning," "deep learning," and "digital architecture," academic articles, books, conference proceedings, and graduate theses indexed in Scopus, ScienceDirect, ProQuest, and Google Scholar databases were archived. In addition, information and documents from reliable websites on the subject were added to the archive to be used as support when necessary. In the next stage, the archive was examined by two researchers using the skimming technique; the ones that could contribute to answering the problem statements and were scientific and unbiased were selected. The selected sources were read in detail by the researchers; notes were taken and discussed in the context of results, discussion, and conclusions. In order to make the analysis process easier and more systematic, themes created in the context of the sub-problems of the research were used. In the last stage, the information obtained was interpreted and presented from a critical point of view.

The precautions taken to ensure the validity and reliability of the research included searching the literature with keywords using reliable databases, including different types of publications in the process, choosing academically accepted publications and reliable internet sources among them, and presenting the results after the publications were examined and discussed by two researchers. In addition, it is thought that the detailed explanation of the studies conducted in the process increases reliability by providing consistency and transparency.

3. Result and Discussion

3.1. The Use of Today's AI Technologies in Architecture

Architects are expected to solve complex design problems at both global and local scales. This process requires a multidisciplinary and collaborative working environment and designers specializing in multiple fields. This situation transforms the design field into a multidisciplinary structure (Trummer & Lleras, 2012). Bringing together intensive data from different fields and various needs at a common point is an issue that needs to be addressed in interdisciplinary studies. AI helps architects make more effective decisions by analyzing data and optimizing design processes. AI has become necessary to manage the complexity brought about by interdisciplinary cooperation and respond quickly to different demands.

In the literature, some studies address different perspectives and applications on the use of AI in the field of architecture, as well as publications that analyze research in this field in depth. Such publications contribute to understanding the current situation and determining future directions by providing comprehensive and holistic information on the role of AI in architecture. The study by Bölek et al. (2023) is a comprehensive source for understanding AI's current and potential applications in architecture. In this study, the effects of AI on architecture are discussed in a multidimensional manner by bringing together research from different disciplines. It examines how AI is integrated into design processes, how it plays a role in solving complex problems architects face, and how these technologies are shaping innovative approaches in the industry. It also discusses future research directions and how AI can be used more effectively in architecture (Bölek et al., 2023). In another study investigating the applications of AI technology in architectural design and its impact on design efficiency, Li et al. (2025) state that AI has great potential in the architectural design process, covering areas such as creative development, data analysis, and problem-solving. The study also emphasizes other applications of AI throughout the building life cycle, such as predictive analysis, construction supervision, and facility maintenance. Through discussing traditional and AI-assisted architectural design methods, the study summarizes the advantages and challenges of AI technology in architectural design (Li et al., 2025).

The reviewed studies make it clear that the integration of AI applications in the field of architecture is an inevitable reality today. Generative design algorithms, AI-powered virtual reality tools, and machine learning algorithms are increasingly integrated into architecture (Almaz et al., 2024). According to Thomas Lane, AI has the potential to take over 37% of the work performed by architects and engineers (Matoso, 2023). In order to demonstrate this contribution more clearly, Table 1 was created by examining the existing AI-supported software (Autodesk, 2025; Spacemaker, 2025; Tesfit, 2025) frequently used in the field of architecture.

Table 1. Comparative analysis of widely used AI-supported architecture software

Properties		AUTODESK Forma	SPACEMAKER	TESTFIT
2D Drawing		✓	✓	✓
3D Modeling		✓	✓	✓
Integration with CAD/BIM		✓	✓	✓
Interactive Design		✓	✓	✓
	Multiple scenario comparison	✓	✓	✓
	Building mass optimization	✓	✓	✓
	Automatic layout generation	✓	✓	✓
	Volume/density compensation	✓	✓	✓
	Zoning/regulation compliance check	Limited	Limited	✓
AI support	Proposal for space use/function	✓	✓	✓
	Visual landscape / corridor analysis	✓	✓	None
	Air flow /wind direction analysis	✓	✓	None
	Daylight analysis and shadow calculation	✓	✓	None
	Noise modeling	✓	✓	None
	Parking lot / traffic flow proposal	Limited	Limited	✓
	Real-time feedback	✓	✓	✓
	Revit / BIM integration	✓	✓	Limited

The software, examples of which are given in Table 1, has automated many tasks that had to be done manually in older-generation software without AI support. Considering the limitations the user sets, relevant regulations, and real-world data, this software can automatically generate many alternative layout plans on a plot of land whose dimensions are entered. Thus, the user can examine these designs and choose among them. Moreover, as in the case of the TestF monitor, this software, thanks to its algorithms based on data analysis, can decide which of the plans they generate is the most appropriate and offer suggestions to the user. Variables such as road layout, building height, and parking requirements are considered. This feature is handy for an architect who does not have enough time to examine many scenarios based on plans. Considering that in previous generation software such as AutoCAD, the layout plan was drawn manually, the ability to quickly create various layout plans for the same plot, compare these plans, and offer various suggestions to the user brings significant gains in terms of time, cost, and workforce. AI-supported software can easily calculate the sun and shadow effect by considering the plot's geographical location, time zone, surrounding structures, natural obstacles, and the orientation of the building. Thanks to this feature, the designer does not need to relocate the light analysis on the model manually. Suppose many new buildings are to be built on a large plot of land in a densely built neighborhood. In that case, it is possible to realize this in seconds with Spacemaker or Autodesk Forma, while the work to be done for each building to benefit from daylight at the maximum level was quite time-consuming in the recent past.

When the studies on the use of AI in architecture are examined, it is seen that approaches based on this technology are primarily used in interactive facade designs and architectural plan production to protect energy efficiency, such as natural ventilation and lighting (Cantemir & Kandemir, 2024). However, the uses of AI in architecture are not limited to these. When the relevant literature (As et al., 2018; Bölek et al., 2023; Cantemir and Kandemir, Ceylan, 2021; Chaillou, 2020; Çelik, 2023; Demir & Akti, 2024; Li et al., 2025; Yıldız, 2025) is examined, it is possible to categorize the increasing usage purposes of today's AI technologies in the discipline of architecture under three main headings as seen in Fig. 1.

Architectural Design

- Conceptual design (idea generation), developing alternative design proposals
- Create a design from text or image
- 3D rapid visualization
- Design-material analysis
- Comparing different design proposals
- Design expression in different forms (audio, written)
- Augmented reality compatible design
- Developing alternative spatial organization
- Parametric design
- Design based on environmental data
- Specific recommendations for urban design
- Detection of errors in technical expression
- Visualization according to different architectural styles
- Increasing the visual richness of 2D and 3D
- drawings
- Data analysis, classification
- Architectural education
- Protection of historical and cultural heritage

Construction

- Modular building element production
- Customized structural element production
- Workforce planning
- Time management
- Construction site productivity monitoring
- Robotics to reduce manpower
- Material and cost analysis
- Material and resource management
- Construction process simulation
- Early detection of errors and risks
- Quality control during implementation
- Occupational safety with image processing supported systems
- Real-time risk analysis
- Design feedback audit based on field data
- Accurate plan application of buildings with sensor-supported systems
- Interactive worker training simulations
- Automatic compliance with local regulations and standards

Building Optimization

- Energy consumption analysis
- Thermal Comfort Analysis
- HVAC optimization
- Building information modeling (BIM)
- Carbon footprint calculation and reduction recommendations
- Maximizing sustainability values
- Effective management of renewable resources
- Structural performance analysis (prediction of structural behavior)
- Monitoring environmental data
- Building health monitoring, estimation of maintenance requirements
- Automated testing of emergency systemsDetermining user satisfaction and adapting the system accordinglyAnalysis of user behavior

Fig. 1. The use of AI in the discipline of architecture

AI is a powerful tool that supports creativity in the architectural design process, facilitates data-driven decision-making, and offers a wide range of contributions from design processes to sustainability practices, from cultural heritage conservation to urban planning. The most prominent of these contributions is the support of idea generation and concept generation in the early stages of design and the exploration of form and structure alternatives in a variety and complexity not previously possible through parametric modeling and generative design methods (As et al., 2018; Hegazy & Saleh, 2023). AI algorithms, mathematical models, and deep learning techniques allow architects to develop innovative design solutions. This accelerates the process and increases the quality of both learning and professional design (Çelik, 2023; Zhou & Park, 2021). In addition, AI is increasingly forming the basis of new methodologies in architectural education and collaborative design processes. In design studios and academic programs, AI-supported platforms can provide students with interdisciplinary thinking skills and develop analytical and process-oriented approaches to the design process (Cudzik & Radziszewski, 2018; Çelik, 2023). Combining AI and 3D printing technology makes it possible to create innovative shapes and forms using fewer materials and resources. In this way, architects can develop creative, non-standard designs.On the other hand, AI helps architects create more design alternatives with fewer materials by providing data diversity (As et al., 2018). This helps to increase both the visual and functional quality of architectural projects. In addition, AI plays a critical role in the development of future-oriented visionary applications in the discipline of architecture. Thanks to its applications that increase both the creativity and efficiency of design, new digital paradigms are being created in addition to traditional methods, making it possible to restructure architectural processes with more holistic, flexible, and data-driven approaches (Harapan et al., 2021). In this respect, AI stands out as a comprehensive tool that enables the physical form-creation process of architecture and the holistic evaluation of urban, environmental, and cultural dynamics (Hegazy & Saleh, 2023; Yiğitcanlar et al., 2020).

Design implementation is the final stage of the architectural planning process. At this stage, the architect regularly visits the construction site to monitor progress, approve shop drawings and material samples, and try to resolve any problems that may arise during construction. The aim is to ensure the final project fulfills the design intent and meets the client's needs. AI also makes significant contributions to the construction site implementation phase of architectural design in terms of accelerating construction processes, reducing costs, and increasing occupational safety. The applications of AI in the construction industry are quite diverse. By using data mining and analytics on construction sites, significant optimizations can be made to complete projects on time. Analyzing data from previous projects helps determine costs and timelines, and AI can predict the requirements of future projects. This way, workflow is facilitated, all project stakeholders are continuously informed, and significant time savings are achieved (Amer, 2023; Matter & Gado, 2024). In addition, AI-supported robotic machines actively assemble and construct ready-made prefabricated building elements, making it easier for workers to produce more qualified work (Amer, 2023; Mathur, 2015). In addition, AI also makes significant contributions to detecting construction errors, production problems, and occupational safety issues on construction sites. Robots and autonomous equipment save time, cost, and labor by performing regular monitoring, data collection, and repetitive tasks in the field. In order to prevent occupational accidents in the construction industry, AI-supported safety systems can be used to identify potential hazards and take preventive measures. In this way, the efficiency of construction processes is increased, and safety standards are raised (Amer, 2023; Matter & Gado, 2024).

AI, which accelerates design and implementation processes, also contributes to architectural practice in building optimization. Wireless sensor networks (WSN), which are used in environmental monitoring and innovative building applications and are becoming increasingly smaller, energy efficient, and economical, collect large amounts of data, and building automation systems (BAS) transform these data into meaningful information (Hu et al., 2024). AI applications are also utilized in energy efficiency studies in buildings. Doukas et al. (2007) developed a rule-based intelligent decision support model for energy management and the comfort level of a building. This model is integrated into the building rnergy management system (BEMS) and has two main sets of rules, one targeting comfort conditions and the other targeting energy efficiency. Tested in an office building in Athens, this AI-powered system resulted in energy savings of approximately 10%. To support energy efficiency in the early stages of architectural design, AI analyzes climate data to optimize natural light, wind, and airflow, recommends building forms that reduce energy consumption, identifies strategic openings for natural ventilation and window placements that maximize sunlight, thus contributing to environmental sustainability while improving building performance (Ceylan, 2021). AI also helps to measure energy use in buildings in areas such as energy saving, heating, cooling, lighting, sensor systems, data mining, emission reduction, and waste management. Thus, it can contribute to achieving the principles of green architecture (Maksoud & Ahmed, 2024). In addition, AI can make the methods used to solve complex engineering problems in structural analysis faster and more precise. AI integrated with techniques such as Finite Element Method (FEM) can be used to evaluate the effects of variable loads such as earthquakes and wind in dynamic analysis. Combined with software such as SAP2000, ETABS, ANSYS, and Abaqus, AI offers more accurate predictions and optimizations for the safety and durability of structures. For example, in earthquake resistance analysis of multi-story buildings or stress analysis of steel bridges, AI can help engineers save time and achieve more reliable results (Hu et al.,2024; Liu, 2020). Another important issue is that AI is critical in post-earthquake evacuation processes with prediction and optimization tools. Systems that model human movements ensure the effective use of fire exits, accelerate evacuation, and prevent panic situations by providing real-time guidance with sensor data (Yılmaz, 2023).

AI makes significant contributions to sustainability, occupational safety, and energy efficiency in architectural design and implementation processes. Increasing creativity in design stages helps projects to be completed on time with data analytics in construction processes. It also strengthens safety practices on construction sites, identifying potential hazards. As a result, AI is supporting adopting more sustainable approaches by increasing efficiency and safety in architecture.

3.2. Current and Potential Risks of AI for the Discipline of Architecture

AI's positive and negative effects are an important topic of discussion for all disciplines. This is also true for the field of architecture. The integration of AI into the discipline of architecture creates both innovative opportunities in design processes and significant professional, pedagogical, and ethical challenges. Research reveals significant limitations of AI on creative processes. Since AI is based on the process of learning from input data, errors in the data directly affect the results (Wang, Cai, & Tian, 2018). Incompleteness, inaccuracies, or errors in data sets can cause AI systems to produce erroneous results. Such errors can cause serious problems in architectural projects, as these results directly affect the safety, functionality, and aesthetic qualities of buildings (Borglund, 2022). Thus, while AI supports humans in quickly understanding the world and predicting possibilities on this basis, it lacks the ability for true creativity and innovative thinking in the context of architecture (Matter & Gado, 2024). This is because the discipline of architecture is different from a simple question with a specific correct answer or option. This is because the architectural process involves many factors, such as the user, political dynamics, social sciences, engineering constraints, environmental standards, and artistic elements, which play an important role in shaping design choices (Gallo & Wirz, 2020). These factors give a soul to buildings, representing a quality that cannot be created by AI alone and are directly related to designers' vision. In this context, the role of AI in the design process is manifested in its capacity to simulate various design alternatives and process large data sets to maintain and validate the necessary parameters such as material use, energy consumption, exposure to natural light, and noise exposure (Borglund, 2022). However, AI cannot create the essence of buildings independently, as it works within the framework of specific rules and algorithms. Although it can produce similar designs based on existing data, it cannot offer original and innovative solutions. This situation shows that architects should work by preserving their creativity and vision while using AI as a tool (Gallo & Wirz, 2020; Haenlein & Kaplan, 2019).

While using AI-supported design tools partially replaces human input in the design process, it may cause the architect's original creativity and critical thinking processes to take a back seat and regress. The results of the research by Fan et al. (2025) reveal that AI technologies such as ChatGPT can trigger meta-cognitive laziness, which can negatively affect architecture students' self-regulation abilities and in-depth engagement in learning. This negativity is related to students' focus on superficial knowledge and weakening critical thinking skills. Furthermore, there is a risk that the analytical and experimental approaches required in creative problem-solving processes will be replaced by AI tools' fast but shallow solutions. As a result, there is a risk of limiting students' capacity to make independent decisions and develop innovative ideas in the design process, which may negatively affect their professional competence and contribution to the field of architecture in the long term. When these risk situations are considered holistically, the new generation of architects must develop different professional skills (Haenlein & Kaplan, 2019). Integrating AI into the educational curriculum allows educators to foster more interdisciplinary and creative design approaches, equipping future architects with the skills required by a digitally driven society (Almaz et al., 2024). The potential use of text-to-visual converters and other generative design tools supports creative idea generation and design exploration. However, traditional educational methods may be insufficient to effectively embrace these advanced technologies, necessitating a fundamental restructuring of architectural education that emphasizes technological competencies and ethical sensibilities (Almaz et al., 2024; Montenegro, 2024). This educational paradigm shift is critical to ensure that the next generation of architects not only benefits from the efficiencies enabled by AI but also retains the human-centered design skills vital to solving modern architecture's complex and interdisciplinary problems (Leach, 2021).

As in many disciplines, the legal and ethical dimensions of the use of AI in architecture need to be addressed. It is a potential risk that AI products and production may lead to intellectual property problems such as copyright. The issues of who owns the design proposals produced by AI and how to interpret the concepts of originality and creative labor are controversial in architecture. These issues are an important risk factor in terms of determining responsibility and property rights for the outputs produced in architectural design (Wang, Cai & Tian, 2018). Data accessibility and accuracy of AI models are among the critical issues for applications in architecture. Designing robust and unbiased algorithms that can handle large and heterogeneous data sources requires a continuous development and strong collaboration between designers and technologists (Bölek et al., 2023; Płoszaj-Mazurek & Ryńska, 2024). On the other hand, the potential biases inherent in AI systems also raise important ethical concerns. If these biases are not carefully managed, decisions made in design processes risk unintentionally reinforcing existing social inequalities (Bölek et al., 2023; Τέλλιος et al., 2023).

In summary, while AI has significant potential to improve architectural design practices by enhancing creativity, efficiency, and sustainability, its integration into this field faces several challenges. Overcoming barriers such as data limitations, ethical concerns, regulatory hurdles, and the need for curricular reform is critical for the harmonious integration of AI into both professional practice and educational institutions.

3.3. Prominent Study Trends and Gaps in the Related Literature

The integration of AI into the field of architecture is a strong area of research that has received considerable attention in recent years. One of the most prominent trends in the literature on AI is the increasing emphasis on its integration with Building Information Modeling (BIM) and sustainability principles. Studies reveal that AI has the potential to optimize design processes to increase energy efficiency and regulate the construction process more effectively in line with green architecture goals (Hegazy & Saleh, 2023; Maksoud & Ahmed, 2024). Integrating AI's predictive modeling capabilities with BIM enables architects to perform complex analyses that consider the environmental performance of a building throughout its life cycle (Maksoud & Ahmed, 2024). The integrated use of these technologies contributes to the development of innovative design solutions that comply with environmental regulations and align with sustainable building practices (Bölek et al., 2023). Therefore, the strategic integration of AI into architecture offers significant opportunities for developing environmentally responsible design approaches in today's climate-sensitive world.

Despite the growing body of literature examining the role of AI in the discipline of architecture, there are significant gaps in understanding the collective impact of these tools on the future of the architecture industry. Much of the existing research often focuses on individual AI tools or specific functionalities, lacking a holistic view of the impact of these technologies on the broader architectural process, including design, project management, and sustainability efforts (Cortiços et al., 2023). Another critical area where existing research falls short is the comparative analysis of AI tools. While studies have highlighted the capabilities of specific tools, such as AI-enabled generative design platforms and AI-enhanced BIM systems, there is a distinct lack of comprehensive analyses that evaluate these tools in terms of their functionality, market scope, and overall effectiveness across different architectural workloads (Zhang et al., 2024). This lack of in-depth and comparative studies prevents architects and industry professionals from making informed decisions about the AI tools that best suit their needs. The absence of such analyses also means that limited guidance is offered on integrating these tools into existing workflows and maximizing efficiency and creativity (Cortiços et al., 2024).

Existing research often ignores the broader professional, economic, and regulatory factors shaping the adoption of AI in architecture. While the technological capabilities of AI tools have been extensively documented, there is limited understanding of the effects of market dynamics, regional differences in technological infrastructure, and variable regulatory environments on the rate and effectiveness of their adoption (Almaz et al., 2024). For example, in regions with advanced technological infrastructure, such as the United States, the European Union, and China, AI technologies are observed to be adopted more rapidly in the field of architecture. In contrast, economic constraints and the lack of supportive regulatory frameworks significantly hinder the diffusion of these technologies in other regions. An in-depth examination of such factors is critical for developing a global perspective on the role of AI in the future of architecture (Alabdulatif, 2024).

Another important gap in the literature is the limited academic discussion on ethical issues in integrating AI into design processes. Critical issues such as biases in algorithmic decision-making processes and the potential devaluation of human creativity have not been adequately addressed (Zakariya et al., 2023). With architects becoming increasingly dependent on AI-generated outputs, an in-depth consideration of how these technologies may inadvertently reinforce existing biases or limit design exploration is warranted. This highlights the importance of multidisciplinary approaches that bring together experts from disciplines such as AI ethics, architecture, and sociology to analyze the impact of AI technologies on design creativity and integrity (Atwa & Saleh, 2023).

The state of educational practices is another important area that is often overlooked. There are frequent findings that current architecture curricula are insufficient to equip students with the competencies to use AI effectively (Jin et al., 2024; Zakariya et al., 2023). In this context, a consensus is emerging on integrating AI technologies and generative design principles into educational frameworks. Blending traditional pedagogies with innovative AI tools can allow students to use technology more informed and empathetic while developing their design capacities (Atwa & Saleh, 2023; Rane, 2024). This transformation will shape future architects' ability to solve complex architectural problems using AI creatively and effectively.

The role of AI in automating processes ranging from conceptual design to project management is increasingly being explored (Rane et al., 2023). Generative design techniques enable architects to generate and evaluate multiple design variations quickly, providing efficiency and innovation in architectural workflows (Bölek et al., 2023). However, many architecture firms hesitate to adopt AI due to the perceived complexity and risks. This transformation requires a change in design processes and an organizational cultural shift that fosters openness to technological innovation. In this context, comprehensive strategies are needed to manage AI integration effectively.

In the literature, there is a lack of empirical studies that quantify the practical effects of AI in architectural practice. While theoretical reviews are common, case studies documenting implementation results and lessons learned in real projects are limited (Baduge et al., 2022; Özman & Selçuk, 2022). Developing an evidence-based understanding of the effectiveness of AI can offer important insights into best practices and potential challenges. Studies addressing successful AI applications can fill this gap, leading to a broader acceptance of AI in architecture (Jin et al., 2024).

In conclusion, while the use of AI in architecture offers significant opportunities for the digitalization and optimization of design, it also reveals significant research gaps based on methodological incompatibilities, data integration gaps, and ethical debates. Therefore, it is of utmost importance that future studies take an interdisciplinary approach that balances both the technical integration and the human-centered and ethical approach to architectural design processes.

3.4. The Future of AI and Transformations for Architecture

Generative design algorithms, AI-supported virtual reality tools, and machine learning algorithms are increasingly integrated into architecture (Almaz et al., 2024). Methods such as AI, swarm intelligence, neural networks, and evolutionary algorithms offer different approaches to design processes. Research shows that AI combined with vision and robotics-based data input-output methods can facilitate architects' daily practices (Wit et al., 2018; Xu, Dixit & Wang, 2024). With the proliferation of applications supported by intelligent algorithms that offer new spatial solutions and run with specialized software, more intuitive and mainstream design tools are expected to be developed. This indicates that AI will transform the architectural profession in many ways shortly. This transformation will cover various processes from design, production, and post-production to user analysis. The study by Cudzic and Radziszewski (2018) draws attention to this situation and states that AI has great potential to transform the discipline of architecture and offer new possibilities.

It is known that AI can not only transform an architectural idea into a design but also make financial calculations, make construction processes more efficient, and provide personalized space optimization by analyzing sustainability and user experiences. This can transform the architectural profession into a ‘coordinator,’ ‘content manager’, or ‘curator’ rather than a ‘designer.’ Although no android architect gets in his car to survey a plot, draws by hand, and works completely autonomously in creativity, some humanoids can assist architects. Some humanoid and quadruped robots developed by the Boston Dynamics company have started to do transportation and simple installation work on construction sites (Boston Dynamics, 2023). It is also known that assistant robots that assist artisans in building walls and robots that perform coating and whitewashing are being developed (Business.govt.nz, 2024; Carros Show, 2025). In architecture, some developments indicate that there may be exciting innovations shortly regarding creativity and the ability to produce original works, which are thought to be the weakest in the professional sense of AI. Ai-Da, introduced as a humanoid with the skills of a performance artist, designer, and poet, is one of these. Described as the world's first ultra-realistic humanoid robot, Ai-Da can create original drawings and paint thanks to the cameras in its eyes, AI algorithms, and robotic arm (Founders Forum, 2024).

The scientific community accepts that AI will transform the profession of architecture, and it is an important research topic being studied. Some universities have centers where related disciplines work in cooperation to ensure the effective use of AI in architecture and to conduct scientific research (University of Michigan, 2023; UT News, 2024). It is not difficult to predict that, in such research centers, projects on training AI to be fully autonomous architects will be implemented shortly.

5. Conclusion

AI, which is used as an auxiliary tool that facilitates work and increases creativity, efficiency, and sustainability in architecture, has started to take on the role of conceptual designer in a short time. Today, AI in architecture offers innovative advantages at many points, from conceptual design to implementation and building optimization to energy efficiency. In particular, generative design algorithms, machine learning, virtual reality, and robotic applications have enabled architects to develop more design alternatives and manage construction processes faster, safer, and more sustainable. The increasing role of robots and automation on construction sites is optimizing workflows, reducing errors, and improving safety. Furthermore, sensor networks and data analytics contribute to analyzing parameters such as energy consumption, environmental impact, and user satisfaction. However, it is argued that AI is still limited in producing originality and innovation in architectural design processes and cannot fully replace human vision and creativity. Quality problems in data sets and the dependence of algorithms on existing data can lead to limited design alternatives and the proliferation of prejudices.

Furthermore, the proliferation of AI-supported tools may weaken architects' critical and independent thinking and risk a superficial approach to information. Existing studies on AI generally focus on individual tools, with significant gaps in holistic analyses, comparative assessments, professional and economic factors, and ethical issues. Issues such as algorithmic biases and devaluation of human creativity are not sufficiently discussed in the literature, nor is the integration of AI in education.

AI technology is developing very rapidly, and applications using this technology are constantly acquiring new skills. This indicates that AI will soon become an integral part of architectural practice and will fundamentally affect architects' job descriptions and working methods. AI-powered tools are assumed to offer architects unprecedented capabilities to analyze complex data sets, quickly evaluate different design scenarios, conduct energy performance simulations, and even create detailed drawings. These developments will speed up design processes, reduce costs, and increase the potential to design more sustainable, functional, and aesthetically rich buildings. However, the current limitations of AI and the need for sensitivity, particularly about regulatory compliance, structural safety, and local cultural context, suggest that the role of the architect as supervisor and decision-maker will remain important. While elements that will remain the cornerstones of architecture, such as creativity, originality, and ethical values, can be imitated by AI, their actual production and contextualization will remain in human intelligence and experience. It is important to embrace AI as a powerful collaborative partner that strengthens architectural design and construction processes, increases efficiency, and opens up new possibilities without seeing it as a threat or a competitor. Architects need to adapt to this new technology, learn to use AI tools effectively and blend the analysis and recommendations provided by these tools with their own creative vision and professional knowledge. The future practice of architecture will be based on a collaboration combining human and AI capabilities, utilizing both parties' strengths to create smarter, more responsive, and more human-centered environments. This collaboration model has the potential to usher in a new era in the evolution of the architectural profession.

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Bridging barriers: Overcoming resistance to digital and computational design in architecture

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Abstract. Despite the transformative potential of computational design and digital tools—such as AI-driven generative design, parametric modeling, and virtual reality—their adoption in architecture remains limited, hindering the discipline's ability to fully exploit technological advancements. This study systematically investigates the barriers to adoption through an extensive literature review, identifying five key areas of resistance: insufficient education and training, high implementation costs, inadequate technical infrastructure, organizational inertia in the construction sector, and ethical concerns related to data security and reliability. The findings emphasize that educational gaps, particularly within architectural curricula and professional training, create a foundational bottleneck by limiting architects' exposure to and understanding of emerging computational tools. Without adequate training, designers struggle to integrate digital technologies effectively into practice, limiting their creative and technical potential. Additionally, the high costs of acquiring and maintaining digital tools, combined with a lack of supportive technical infrastructure, further exacerbate adoption challenges, particularly for small and mid-sized firms.

Moreover, the construction sector's resistance to change—rooted in conservative workflows and risk-averse management structures—hampers collaborative efforts needed to integrate innovative digital solutions across design and construction phases. Ethical concerns regarding data security, privacy, and the reliability of AI-generated outputs also contribute to hesitation among stakeholders, creating a need for more robust frameworks that address these challenges. To overcome these obstacles, the study proposes a multi-pronged approach: integrating computational design into core architectural curricula, promoting interdisciplinary collaborations between academia, industry, and technology firms, and implementing sector-specific policies designed to enhance digital literacy and reduce economic and infrastructural barriers.

By offering actionable recommendations, such as establishing industry-academic partnerships, incentivizing digital upskilling, and creating financial support mechanisms for adopting digital tools, this research aims to bridge the gap between theoretical innovations and their practical applications in real-world projects. Ultimately, the study argues that a comprehensive approach to digital integration can foster greater innovation, sustainability, and creative exploration in architectural practice, transforming both the design process and the built environment. By addressing the current limitations, this research lays the foundation for a more adaptive, digitally-driven future in architecture, where technological tools become essential contributors to design excellence and project efficiency.

Keywords: Computational design; Digital design; Artificial intelligence; Barrier; Architecture

1. Introduction

Emerging technologies are transforming architectural practices in unexpected ways, a change that many could have not predicted just a decade ago. In terms of concepts and design, traditional systems are being replaced by computational and digital arhitectures. Digitally guided design proces are enabling new architectural possibilities. The creative and generative potential of digital technologies is beginnig to offer innovative approaches in architectural design, similar to advancements of other diciplinces (Koloreviç, 2004). It is also anticipated that, advances that lead to major changes in other diciplinces will be reflected architecture dicipline (Caetano & Leitão, 2019). However architects tend to be late in adopting technological change (Carpo, 2017). This process, which progresses more slowly in the field of architecture compared to digitalization in other diciplines constitues the main problem. The adoption of digital design is seen as inevitable to close the gap between the virtual context and physical production that emerges with the development of technology (Dritsas, 2012). While some argue that this change has the potential to develop much more than architectural styles, there are also critics (Carpo, 2024). In a study conducted in 2014 in the field of digialization in architecture, identified several challenges as to slow digital

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adaptation and criticism. These barriers in digital design are seen as thresholds to be overcome in front of the mentioned and expected transformation. However, the lack of adoption or inhibition of these technologies weakens the relationship between the discipline of architecture and technology (Ramilo & Embi, 2014). It is believed that the relationship between digital design and technologies will contribute to the bacis dynamics of architecture and provide an environment for more effective and faster design solutions. In this context, design approaches that are thought to have the potential to transform not only today's architecture but also future architectural practice, are seen as the pioneers of a great transformation. Therefore, it is important to examine why this change has not been realized for the digital transformation to be experienced healthily. This research aims to determine the resistances encountered in the process of digitalization in architecture, especially with the new technologies developed in the last five years. Identifying the resistances and the approaches to overcome them will provide an understanding of the current state and future potential of digital design. In this context, the research focuses on the following questions:

1. What are the history and nowadays approaches of digital design in architecture ?
2. What are the innovative approaches and tools used in process of digital design ?
3. What kind of resistance is encountered in the adoption of these processes?
4. What are the solutions that can b developed to overcome these barriers ?

This study aims to reveal current limitations encountered in the process of digital integration in architectural practice and offer soluttions to overcome these limitations. In the introduction section, the aim and scope of the research are explained by evaulating the historical development and curret situation of digital design. The process of research, the methods used and the litarature review are detailed in the material and methods section. In results and discussion section, the classification of digital tools and the analysis of the resistance to adaptation of these tools are represented. The suggestions for overcoming these resistance and the findings are evaluated with holistic approach in the conclusion section.

1.1. Perspectives of Digital Design

Digital design has the potential to transform the practice of architecture, rooted in computational design—an approach that uses algorithms to generate, analyze, and optimize architectural solutions. The foundations of computational design date back to the 1960s (Terzidis, 2003; Dritsas, 2012). The Shape Grammers was developed by George Stiny and Jim Gips are shown as important examples in this period (Knight, 2024). Computational design approaches enable the production of complex forms more effectively and can be classified into parametric, algorithmic, and generative design (Caetano, Leitao, & Santos, 2020).

Over time, these approaches have supported by advancement of digital tools. In this context, digital design refers to a process where digital technologies play an active role from sketching to modelling and from visualization to performance analysis (Dritsas, 2012). The introduction of CAD (Computer Aided Design) technologies into architectural practice in the early 1980s marked a significiant transition from traditional drawing methods to digital production. These tools not only accelerated production process but also expanded creative potential (Kolarevic, 2004; Chaillou, 2022). However, since CAD usually can not go beyond digitising the drawing, BIM (Building Information Modelling) systems were developed in 2000s to overcome these limitation. BIM has created a crucial milestone in digitalization by integrating processes such as conflict detectin, cost analysis and sustainability assesment into a comprehensive platform (Bernstein, 2022). Parametric design which formulates a design's form based on a spesific parametres, gained popularity after Patrik Schumacher outlined its fundamental principles in his manifesto (Kolareviç, 2003; Chaillou, 2022). Currently, the most advanced aspect of digital design is artificial intelligence aided generative design. Generative design add ons to CAD, BIM and parametric design software make the design process more data-driven and optimized. Artificial intelligence has evolved beyond a mere drawing tool to become a collaborative partner in the design process, directly contributing to decision-making and providing suggestions (Leach, 2022).

Despite these technological advancements, digital design has not been widely and effectively adopted in architectural practice. The reasons for this slow technological adaptation, particularly in comparison to other disciplines, are debated—whether they stem from rational needs or biases remains unclear. In a world where technological innovation is accelerating daily, various factors such as cultural, social, technical, and economic reservations against technology contributed to this situation (Carpo, 2024).

Consequently, in order to fully utilise the potential of computational and digital design, it is necessary to identify the factors that hinder the adoption of these technologies and develop constructive approaches on how to overcome these resistances. Digital technologies add value to architectural practice not only in terms of efficiency but also creativity, sustainability and holistic design approach. Overcoming the obstacles to integrating digital technologies is critical for fostering awareness that computational design can provide transformative value to the field of architecture, rather than merely serving as an instrumental tool.

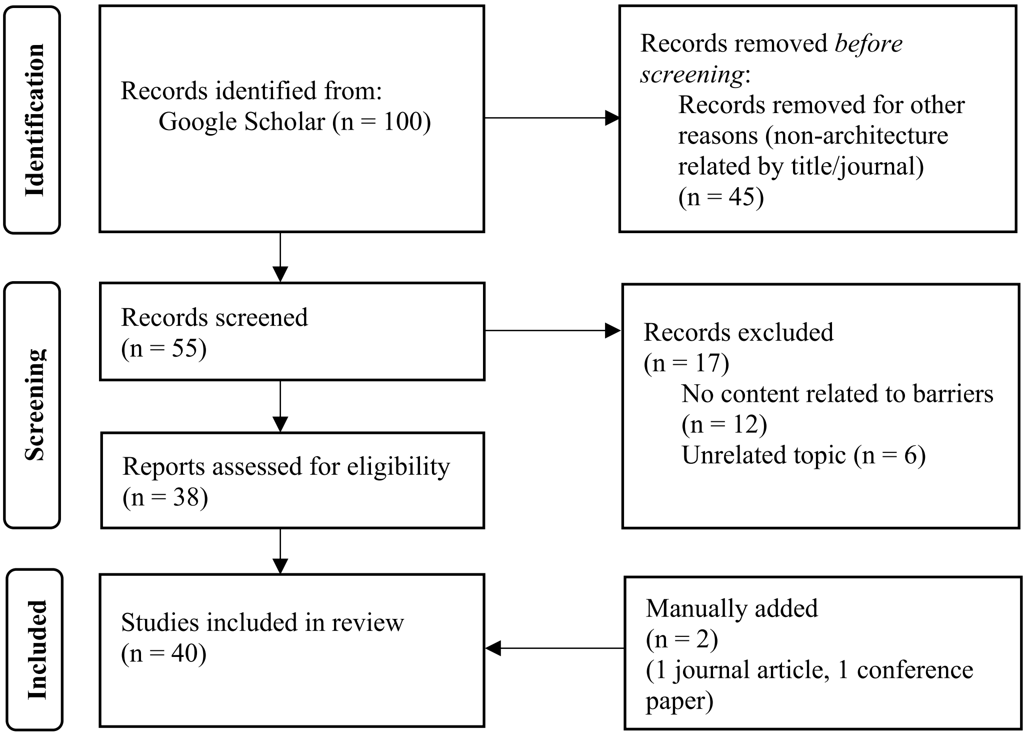

Fig. 1. Revised PRISMA 2020 flow diagram. Adapted from Page et al., 2021.

2. Materials and Methods

The study aiming to evaluate computational design and digitalization process and to identify resitances in the adaptation process, has conducted a literature review focusing on the barriers to digitalization in the field of architecture. The research was conducted through Google Scholar using the following keywords (Table 1.)

Table 1.

Function	Keywords
Google Scholar	architecture AND digitalization AND digital design OR artificial intelligence OR computational design AND barrier OR obstacle

The search covered publications from 2019 to 2024, with results sorted by relevance. The first 10 pages, which included approximately 100 articles, were manually analyzed. From these initial 100 records, 45 articles were eliminated for being irrelevant to the field of architecture based on their titles and journals. Additionally, 17 articles were excluded after abstract screening due to a lack of thematic alignment with the research focus.

After this screening process, 38 articles remained for full-text evaluation. Furthermore, 2 manually selected publications—one journal article and one conference paper—that met the study criteria were included. Thus, a total of 40 publications formed the basis of this literature review. The selection process adhered to the PRISMA 2020 flow diagram guidelines for systematic reviews involving only databases and registries (Fig. 1.). Following the analysis of the available resources, frequently used digital design tools were identified using Voyant Tools. Descriptions of these tools and their applications in the context of computational and digital design were provided. The digital tools were categorized into six headings: geometry and form generation, performance and optimization, data and information management, representation and visualization, generative design, and physical production. Once the digital design tools were determined, the data obtained from relevant literature were further analyzed using Voyant Tools. The most common barriers were grouped into five categories: education, construction, economy, technical issues, and ethics.

3. Results and Discussion

3.1. Digital Tools

The analyzed articles incorporate various digital design tools, physical production methods, and innovative approaches into architectural design. These tools are organized into six categories: geometry and form generation, performance and optimization, data and information management, representation and visualization, generative

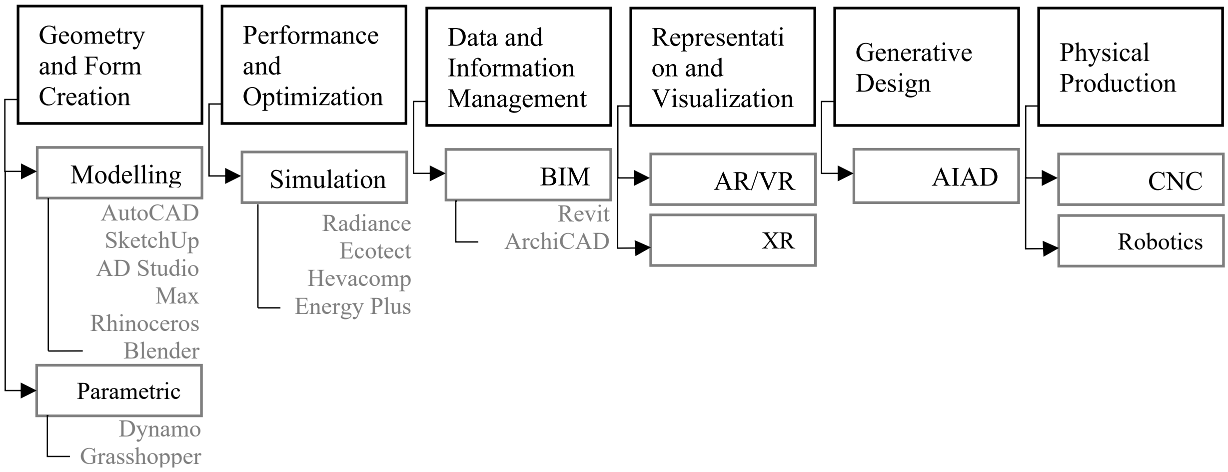

Fig. 2. Classification of digital tools (Source: by authors)

design, and physical production. Under the heading of geometry and form generation, modelling and parametric design tools, simulation tools under performance and optimisation, BIM tools under data and information management, augmented reality, virtual reality and extended reality technologies under representation and visualisation, artificial intelligence assisted design under generative design and CNC manufacturing, robotic manufacturing and digital fabrication technologies under physical manufacturing are mentioned (Fig. 2.)

3.1.1. Geometry and Form Creation

They are tools for creating bacic form and geometries in 2D or 3D in design process. It is examined under two headings as modelling and parametric tools. While modeling tools enable designers to create geometric forms in two- or three-dimensional spaces, parametric design tools enhance this process by utilizing parameters and algorithms to generate multiple design alternatives. These tools, employed at various stages from concept design to detailed technical drawings, assist designers in producing aesthetic and optimized designs, significantly contributing to increased creative potential (Koloreviç, 2003).

The use of digital tools in architecture began with the advent of CAD in the 1960s, allowing designers to explore new forms and structures. This shift introduced concepts such as flexibility, adaptability, and accessibility into the field of design (Giresun Erdoğan & Kutsal, 2024). With advancing technology, the integration of computers into architecture became widespread in the 1980s. During this period, known as "Computer-Aided Design," designers transitioned from traditional manual methods, like rulers and squares, to using a keyboard and mouse (Yıldırım, 2023). Popular non-parametric modeling and 2D drawing tools include AutoCAD, SketchUp, 3D Studio Max, Rhinoceros, and Blender (Algassim et al., 2023; Dauda et al., 2024; Ramilo & Embi, 2014).

Parametric design tools, which incorporate coding methods during the design phase, allow for more flexible and creative designs compared to BIM software (Yıldırım, 2023). The growing adoption of parametric design is gradually evolving into a design philosophy (Soleimani, 2019). One of the most significant advantages of using parametric design tools in architecture is their ability to create building models focused on performance. Examples of parametric design tools include Dynamo and Grasshopper (Delikanlı & Çağdaş, 2021; Ramilo & Embi, 2014). Moreover, by integrating parametric design tools with artificial intelligence algorithms, designers can create more flexible and intelligent designs aimed at various objectives (Yıldırım, 2023).

3.1.2. Performance and Optimization

The performance and optimization tools are used to optimizate design process and to do performance oriented designs. The simulation tools are included in this heading. Simulation tools, used in building performance modelling, are the an another area of digital design. It provides to comprehensive new approach to the design of built environment qualitative and quantitative methods as well as numerical design technologies (Koloreviç, 2003). The sotwares like Radiance, Ecotect, Hevacomp and Energy Plus are used the area of simulation in the design process. With these tools, factors such as energy efficiency, indoor humidity and air flows can be analysed and can be created based on them (Ramilo & Embi, 2014).

3.1.3. Data and Information Management

Under the heading of data and information management, BIM toola are examined. These systems, ensure that data sharing and integration at many stages from design to construction and operation process, provied a more collabrotive evironment in architecture, construction and engineering sectors. In this way, the design process becomes more transparent and efficient (Sacks, Eastman, Lee, & Teicholz, 2018).

BIM technology, in which both 2D drawings are created and the 3D model of the building can be created practically according to these drawings, is widely used in the architecture sector. With the developing technologies, BIM tools also have new integrations based on the use of parameter (Dauda et al., 2024; Elagiry et al., 2019; Olowa et al., 2023; Perez et al., 2022). The tools like Revit and ArchiCAD provide that the users form different diciplines work on the same platform during design and construction process. In this way, the error rate in projects is reduced while cost and time management are well controlled (Ershadi & Lijauco, 2024; Perera et al., 2023; Van Tam et al., 2024; Waheed & Abbas, 2023; Wu et al., 2021).

3.1.4. Representation and Visualization

AR (Augmented Reality), VR (Virtual Reality) and XR (Expanded Reality) are examined as representation and visualization tools that provide enhanced experiences. AR and VR technologies transcend the boundaries of physical reality, enabling the creation of dynamic, adaptive and interactive spaces (Giresun Erdoğan & Kutsal, 2024; Guray & Kismet, 2021). AR and VR in architecture are innovative technologies which especially enhance the BIM process. AR enriches physical space with virtual elements while VR creates immersive environments that represent real-world spaces. These technologies are valuable throughout various stages of the architectural design like visualization of project, communication, education and decision-making. In addition, the ability of AR and VR integrate with BIM makes these technologies more efficient (Gardner, n.d.; Jin, 2024; Noghabaei et al., 2020). AR combines the physical world digital data, enabling more accurate visualization during construction process. The project team can communicate efficiently in this manner. VR technologies provide that the design process more interactive. In this way, designers and engineers can experience the project in a virtual space, allowing them to make decisions quickly and accurately (Mousavi et al., 2024; Soleimani, 2019)

Architectures can design spaces without physical limitations and costs in the digital design realm. The Metaverse offers an environment that promotes flexibility and creativity, shaping both design process and experiences of users. For these reasons, digital tools like the Metaverse are essential for the future of architecture (Erdoğan & Kutsal, 2024).

3.1.5. Generative Design

The roots of artificial intelligence (AI) stretch back many years, but the concept was first introduced by John McCarthy in 1956. Today, artificial intelligence, still in the early stages of development, is viewed as a crucial component of the future (Leach, 2021). The use of AI in architecture and construction increases with developing technologies. The stages such as the design process, material selection, data analysis, time management and risk assessment become more effective with AI. These technologies transform architectural practice and its intellectual structure, are important for the future of the sector (Yıldırım, 2023). The widespeard use of AI is also seen in the construction sector. Researchs has shown that the use of AI can improve safety and productivity in the construction process (Liang et al., 2024). The text-to-image models such as Stable Diffusion, DALL-E 2 and Midjourney are frequently utilized by architects and researchers during the creative design process. AI can be used in different stages of design like conceptual image design, architectural 3D form design, floor plan design, facade design, structural system design and section design. Despite these advantages, they are still some reservations regarding the application of generative AI in architectural design (Li, Zhang, Du, Zhanga, & Xie, 2024).

3.1.6. Fhysical Production

Digital fabrication technologies encompass tools such as 3D printers, robotic fabrication systems, laser scanners and CNC machines. These tools have significiantly transformed design and production process in architecture, enabling designers to create more innovative, efficient and customized structures (Koloreviç, 2003). With these technologies, prototypes and actual structures can be produces using a wide variety of materials, including plastic, metal and ceramic. These tools facilitate the conversion of geometries generated through parametric design approaches into tangible products, enhancing the interaction between the digital and physical realms (Knippers et al., 2021; Sorguç & Yemişçioğlu, 2020). They also allow for the exploration of new materials and structural elements, offering high precision and efficiency in the production process. In addition, these technologies provide advantages such as real-time data collection and visualization during project management and construction. As a result, structures can be digitally modeled on site, allowing for the early detection of inconsistencies and errors between design and construction (Celoza, 2024; Soleimani, 2019).

3.2. Barriers of Digitalization

In the literature review conducted to understand the barriers to the adoption of these technologies in digital design, five areas particular stand out. are attracted in the literature review. Although some of these areas are not directly

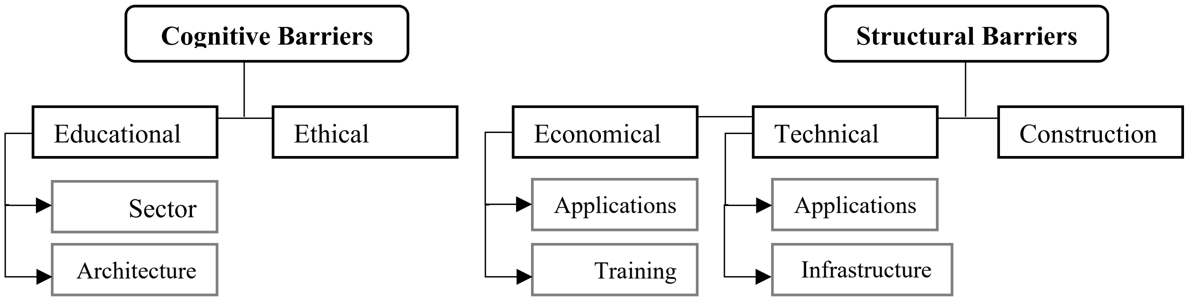

Fig. 2. Classification of barriers (Source: by authors)

related to architecture, they cause barriers to the adoption of digital technologies. The cognitive barriers arising from human-centered and cultural factors, such as lack of knowledge and ethical reservations are divided into education and ethics. The structural barriers arising from the systems, sectors or infrastructure, are categorized under three headings; economic, technical barriers and construction sector (Fig.2.).

3.2.1. Educational Barriers

Education is seen as an important barrier to become widespread these technologies. The general lack of knowledge about computational design and digital design, is mentioned in the conducted articles. This problem of education is analyzed under two headings, education in architecture and sector.

Various studies in the architectural sector highlight a significant issue: many firms lack knowledge in adopting digital design technologies. The primary challenges arise from insufficient skills and a general unawareness of these technologies. Firms that resist change, fail to invest in training, and maintain outdated practices create substantial obstacles to the integration of these advanced technologies (Abhari & Abhari, 2020; Adeusi et al., 2024; Desouki et al., 2023). A study has revealed a significant shortage of skilled and experienced professionals capable of implementing BIM design. This shortage can be attributed to several factors within the industry, such as uncertainty in market demand, general policies, and legal frameworks. Algassim (2024) attributes this inadequacy in the sector to the reactionary attitudes of major industry players. Additionally, Perez et al. (2022) emphasize the necessity of digital transformation while pointing out the lack of incentives for training within architecture and construction firms. Although computational design skills are becoming increasingly essential, they alone will not suffice for a successful transformation. Therefore, we need architects who are fully proficient in these technologies (Celoza, 2024; Perez et al., 2022). Computational design determines what is done as well as how it is done. Therefore, it is necessary to have these skills to adapt to this change. Providing these skills, which are seen as a major deficiency, is possible only if managers provide both the necessary training and a suitable working environment (Bajpai & Misra, 2021; Brozovsky et al., 2024).

According to findings on architectural education, some universities include computational or digital design in their curricula, but it is often treated merely as a tool (Sorguç & Yemişçioğlu, 2020). Gaps in education and existing prejudices hinder the acquisition of these new skills, posing significant challenges that need to be addressed in architectural education (Adeusi et al., 2024; Brozovsky et al., 2024; Cao et al., n.d.). This resistance contributes to a considerable delay in adopting new generative AI models, particularly in the area of computational design. Utilizing AI algorithms in architecture requires extensive specialized knowledge, and architects often struggle to keep pace with rapid technological advancements. As a result, many continue to rely on traditional design processes (Grajeda-Rosado et al., 2024; Li et al., 2025). Additionally, there are reservations about using digital spaces, such as the Metaverse, in architectural education. Concerns about the potential for digital experiences to distract individuals from real-world issues, integration challenges for designers, technological limitations, and the risk of diminishing creativity all impede the adoption of these platforms (Giresun Erdoğan & Kutsal, 2024). However, with the evolution of architectural education, fostering computational thinking skills will help bridge the gap between rational sciences and information technologies. This connection can lead to the exploration of the untapped potential of computational design (Delikanlı & Çağdaş, 2021)

3.2.2. Ethical Barriers

Ethics has been found to play an important role in the adoption of digital transformation. Ethical reservations of architects, students or construction sector employees were identified as another obstacle behind not using these technologies.

In the research conducted, several ethical and reliability issues have emerged, particularly in the field of artificial intelligence. Prejudice against AI tools due to their reliability risks hampers their adoption. This complex problem necessitates the development of an ethical framework for the implementation of AI in project or construction management (Onatayo et al., 2024). These technologies gather data during the design phase for management purposes, such as monitoring, work control, and documentation. Some of the data collected may include information irrelevant to the project's objectives, leading to potential data privacy violations. Concerns about data privacy limit the use of digital design tools and complicate their adoption by stakeholders in the industry (Liang et al., 2024). Watanabe (2014) examined common issues like data privacy, over-reliance on algorithms, and a disregard for technology's limitations, concluding that both students and professionals have decreased trust in digital technologies due to insufficient discussion about data privacy and the implications of computing. The lack of ethical considerations has turned technology into a means to an end. Data transfer processes often create environments vulnerable to data leaks, unexpected changes, or damage, which can lead to private data breaches and make systems untraceable (Liang et al., 2024; Montenegro, 2024; Rane et al., 2023). Addressing these concerns will strengthen the ethical foundations of digitalization and facilitate the wider adoption of digital technologies in the sector.

3.2.3. Economical Barriers

Barriers to the adoption of these approaches include economic and financial problems. Economic constraints are divided into two sub-headings: implementation cost and training cost. In the studies reviewed, it is pointed out that the software and the programs used are inaccessible due to their cost. In addition, it has been determined that even if they have these software, managers who want to increase the level of training resist change due to the cost of training.

Algassim (2024) notes in his study that the high cost of acquiring the most innovative digital technologies presents a significant barrier for organizations. This high price, along with the inaccessibility of these technologies for small and medium-sized firms, poses a challenge that must be addressed for change to occur. The hardware and software required for digital design are perceived as more expensive and complex compared to traditional design methods (Giresun Erdoğan & Kutsal, 2024). Additionally, adopting digital means of production often entails various investment requirements, causing companies to hesitate in allocating resources to digital environments (Ajirotutu et al., 2024; Ramilo & Embi, 2014; Waheed & Abbas, 2023). The adoption of virtual reality (VR) and augmented reality (AR) technologies in architecture is also limited by economic barriers. The costs associated with implementation not only impede technology adoption but also result in the under-utilization of their potential benefits. Addressing these economic obstacles could encourage greater acceptance of these technologies (Mohammadi & Martins, 2023).

Economic barriers extend beyond implementation to the experiential aspects that these applications demand. Employee-related costs, including training and support, further complicate the adoption of these technologies in the industry (Bajpai & Misra, 2021; Mohammadi & Martins, 2023). The projected training expenses for architects lacking the necessary skills have deterred some professionals from pursuing these technologies (Perez et al., 2022). A study concerning the use of generative design in architecture highlights that integrating computational design tools into project management systems requires significant investments in training. For instance, projects incur additional costs for training and maintaining a generative AI model, which slows down the adoption process. These extra costs pose a substantial barrier for stakeholders, particularly for smaller companies (Onatayo et al., 2024).

3.2.4. Technical

The lack of technical infrastructure, which is one of the obstacles to digitalization, is also mentioned in the studies. In the non-adoption of technology, the fact that the software is not accessible and does not have the appropriate infrastructure for it to work are cited as reasons for the lack of acceptance of digitalization.

Certain software and programs are essential for computational design and the implementation of new technologies. Their availability and accessibility are viewed as critical factors for widespread adoption. The articles reviewed present differing opinions regarding the adequacy of these software solutions. For instance, the technical difficulties associated with these applications, along with their lack of user-friendly interfaces, contribute to their unpopularity (Chatzikonstantinou, 2021; Cheung & Dall'Asta, 2024; Perera et al., 2023). Additionally, security concerns regarding these applications are also considered significant issues (Van Tam et al., 2024; Xu et al., 2021).

There are various viewpoints on the deficiencies in the infrastructure necessary for effectively using these technologies. Sorguç (2020) argues that the increasing ease of use of software plays a vital role in this transformation. In contrast, Perez (2022) highlights that a lack of technical support is equally crucial, suggesting that providing training alone may not be enough. A successful digital design experience is contingent upon meeting the hardware and software requirements necessary for access. Technical infrastructure challenges during the design process can hinder efficiency and slow down progress (Giresun Erdoğan & Kutsal, 2024). However, some studies criticize these obstacles. They point to the challenges imposed by the pandemic and the revelation of existing, underutilized infrastructures as examples of potential remedies (Carpo, 2024).

3.2.5. Construction

One significant factor hindering the adoption of modern design processes is the construction industry itself. The studies reviewed revealed that varying attitudes within the sector contribute to its resistance to these changes. There are differing views on why the construction industry is lagging in this regard.

For instance, Carpo (2023) criticized the construction sector as a reactionary and conservative "dinosaur" in its approach to innovation. He describes today's construction industry as a monument to wastefulness, characterized by inefficient and unsustainable building practices. Studies indicate that the construction industry has the lowest level of digitalization and adaptation to change compared to other sectors. This resistance is largely due to concerns about rising costs. Although there have been efforts to encourage the integration of technology in construction, these initiatives have primarily focused on BIM and its incremental improvements. As seen in other fields, true transformation requires embracing advancements in technology. The sector's stagnation is viewed as a major barrier to this transformation. Algassim (2024) cites the rapid construction of a hospital in Wuhan, China, which was completed in just ten days using digital technologies, as a striking example of the construction industry's reluctance to step out of its comfort zone. This project, which typically takes an average of ten years to complete, highlights the potential for efficiency when forced to adapt. Innovations in the industry should not only focus on enhancing existing processes but also on exploring the broader potential of these technologies (Knippers et al., 2021). Additionally, another study within the construction sector points out a lack of contextual input that aligns with the industry's complexity in areas such as structural, mechanical, electrical, plumbing, and project management. Defining and measuring the sector's goals in a manner that an AI model can understand and optimize presents challenges rooted in cultural and social factors. These obstacles further distance the construction industry from adopting advanced technologies (Onatayo et al., 2024).

4. Conclusions

Digital design's adoption of tools and processes emerging with developing technologies is an important step of digitalization in the field of architecture. This change has also affected the processes of thinking, working, designing and producing in architecture. However, there are some obstacles that cause these changes to be adopted later in the field of architecture than in many other disciplines. Due to these obstacles, problems are encountered in the use of digital design technologies. As a result of the literature review, different views were identified and ranked against the resistances affecting the adoption of the mentioned technologies in architecture (Fig.3.). According to this ranking, the most common resistance in the field of digitalization is education. The obstacles encountered in the field of education are mostly due to the lack of education in the sector. These problems are listed as follows:

- Lack of awareness and understanding of digitalization in the sector
- Lack of specialized people and practical training in the sector
- Skills gaps between professionals
- Prejudice against learning and professional development in the sector
- Inadequate collaboration between architects and IT professionals
- Lack of incentives for continuing education

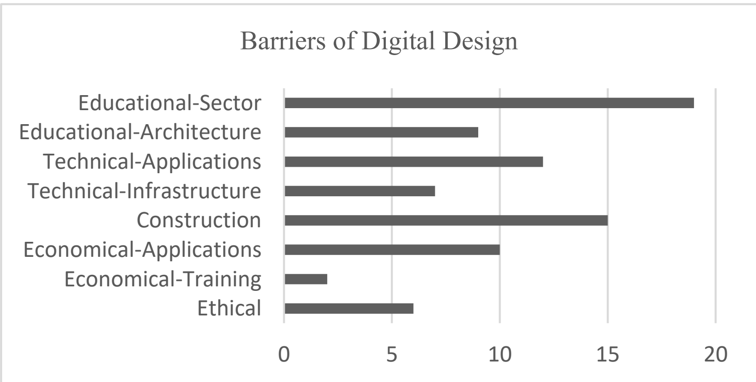

Fig. 3. Barriers of digitalization in architecture (Source: by authors)

The difficulties in architectural education, which is another title where problems in the field of education are seen, are listed below:

- Unrenewed architecture curriculum
- Failure to integrate BIM and digital tools into education
- Limited exposure to emerging technologies in schools
- Lack of formal training on AI/digital tools

- Lack of training programs at university level
- Lack of awareness and skills among students

In the second place, these barriers are most common in technical areas. The technical barriers experienced in digital design tools are listed below:

- Software that is difficult or complex to use
- The “black box” nature of AI tools
- Interdisciplinary incompatibility (architecture and computer science)
- Difficult technical processes requiring expert intervention

Infrastructural problems, another heading of the technical field after digital applications, are listed as follows:

- Lack of infrastructure, standardization and regulation
- Data interoperability issues
- System compatibility issues
- Inadequate data security measures

In the construction sector, which ranks third, the resistances affecting digitalization in architecture are listed as follows:

- General resistance to change and low adoption in the construction industry
- Conservative practices and habits
- Organizational resistance and leadership gaps
- Lack of awareness in construction companies

One of the reasons for the economic barriers in the fourth row, resistance in implementation costs, is listed below:

- High cost of software and hardware
- Expensive license fees and infrastructure
- Budget constraints for digital transformation

The problems encountered in employee training, another heading of economic barriers, are listed below:

- High cost of professional training programs
- The financial burden of continuing education
- Costly transition for teams and organizations

The fifth and final heading, ethical resistances, is listed as follows:

- Data privacy and security concerns
- Algorithmic bias and its ethical implications
- Job security concerns related to automation
- Lack of ethical framework and guidance in the use of AI

Overcoming these resistances faced by the digitalization process, which has the potential to transform the field of architecture, will accelerate the digital transformation process by enabling easier adoption of technologies. Different solutions to overcome these resistances have been proposed in the literature (Table. 2.).

Table 2. Recommended solutions for barriers of digitalization

Barrier	Explanation	Recommended Solutions
Educational	Insufficient knowledge of digital tools among students and professionals	Integration of AI, data science and computational design into the curriculum, certificate programs, mentoring systems, online courses
Ethical	Data privacy, algorithmic biases and human-machine interactions	Increasing ethical education, adopting a people-oriented
Economical	High costs	Long-term benefit and return on investment analysis
Technical	Lack of infrastructure and technical skills required for the integration of new technologies	Creating the necessary technical infrastructure, ensuring that architects are familiar with the applications
Construction	Adherence to conventional methods	To more clearly demonstrate the economic benefits of digital tools in the construction sector and create strategic plans

One of the most common sources of resistance to digital transformation is the lack of knowledge regarding digital technologies, both in the industry and in architectural education. In this context, Onayato (2024) advocates for the inclusion of courses on artificial intelligence, machine learning, and data science in university curricula as a solid foundation for digital transformation. Interdisciplinary programs and specialized courses can help students adapt to digital tools at an earlier age. This approach will encourage architects to adopt more collaborative and technology-sensitive methods in the future (Onayato, Onososen, Oyediran & Oyediran, 2024). A study utilizing digital design tools found that 91.7% of students indicated they would use computational design in their careers, while 45.4% believed this course should be mandatory. These findings underscore the necessity of introducing students to these technologies and providing them with hands-on experience in design studios, as well as in theory and structure courses (Soleimani, 2019). Consequently, architectural education should not only focus on technical skills but also promote a design thinking approach that critically assesses the potentials and limitations of digital tools (Sorguç & Yemişçioğlu, 2020).

It's also essential to consider the ethical dimensions of technology. Watanabe et al. (2014) highlight that a lack of ethical considerations can undermine trust in technology, turning it into an end rather than a means. Thus, a greater emphasis on ethical issues by educational institutions and professional fields can guide healthy human-computer collaboration. Carpo (2024) stresses that technologies should be regarded not as "the future" but as "today's reality," and architects must take responsibility for shaping the future by embracing these technologies. In this regard, universities should not be the only institutions involved; certificate programs, workshops, and online training opportunities in the sector also play a critical role in helping architects adapt to the digitalization process. These resources—which cover areas such as programming, data management, and artificial intelligence—are instrumental in bridging knowledge gaps. Furthermore, mentorship programs fostering knowledge sharing among experienced professionals in the industry are also valuable. By taking these hands-on approaches, AI-based solutions can be more effectively integrated into architectural practice (Onayato et al., 2024). It is vital for the sustainability of the transformation process that the industry comprehends digital transformation, identifies existing gaps, and develops appropriate strategies (Higgins, 2023).

In the construction industry, various factors contribute to resistance, including cost concerns, reluctance to abandon established habits, and issues related to ease of use. However, Mohammadi (2024) asserts that VR technology is likely to become a reasonable investment for construction companies within five years. During this transition, companies must conduct economic evaluations that align with their projects. A study by Noghabaei et al. (2024) suggests that the majority of young architects predict that BIM and AR/VR technologies will be widely adopted in projects within the next 5-10 years. This expectation illustrates the rapid acceptance of digital technologies within the sector.

The research highlights several key factors that hinder the digital transformation process in the construction sector. These include deficiencies in education, high costs, a lack of technical infrastructure, traditional practices in the industry, and ethical concerns. One significant finding is the need to restructure architectural education to incorporate digital skills, as the current lack of knowledge in this area poses a major barrier to the effective and innovative use of digital tools. To facilitate the adoption of these technologies, it is crucial to establish cross-sector collaborations and develop policies that address both economic and technical challenges.

The research not only identifies sources of resistance but also suggests practical solutions to accelerate digital transformation. Key proposals include increasing digital literacy in education, developing sector-specific digital strategies, and creating frameworks that promote the ethical use of technological tools in architectural practice. In conclusion, the comprehensive integration of digital technologies into architecture can lead to a more innovative, sustainable, and human-centered future for the construction industry. This shift will redefine not only design processes but also the theoretical and practical boundaries of architecture.

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From notes to structures: Translating musical composition into the architectural realm

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Abstract. Throughout history, architecture has been regarded as both a design discipline and an artistic endeavor. By its very nature, this artistic dimension has compelled architecture to maintain close ties with sculpture, music, dance, theater, and literature. Over the centuries, the relationship between architecture and music has been analyzed from various perspectives by philosophers, literary figures, architects, musicologists, and design theorists. Notably, in ancient Greece, mathematical theorists sought to establish arithmetic relationships between musical and architectural works, and similar connections have continued to exert an influence into the modern era. Philosophers and literary scholars, in contrast, primarily addressed the relationship between music and architecture in symbolic and metaphorical ways, without fully exploring their shared structural and design languages. Despite the distinct ways in which architecture and music are perceived, it is evident that their creators—architects in the case of architecture and composers in the case of music—exhibit parallels in their modes of thought, design processes, design principles, and structural characteristics. When both disciplines are viewed as products of design, indirect connections can be observed in their creation, presentation, and reception. Moreover, the outputs of both disciplines qualify as compositions, each organized according to a specific design framework. This study aims to explore various facets such as the relationship between music and architecture, the translation of music–architecture interaction into the design realm, and the influence of music on creativity in the architectural context.

Keywords: Architecture; Music; Basic design; Education; Creativeness.

1. Introduction

"*The sense of physical space in architecture manifests as an emotional space phenomenon in music, creating a hybrid relationship between the two disciplines*" (Denari, 1994).

Although music and architecture appeal to different senses, they share a strong relationship through common design principles such as rhythm, proportion, harmony, and composition. Architecture shapes space to establish a visual order, while music structures time to create an auditory order. However, both disciplines guide human perception, evoke emotions, and offer aesthetic experiences. Throughout history, architectural spaces have been specifically designed for musical performances; structures such as cathedrals, concert halls, and theatres have shaped the musical experience through their acoustic and spatial arrangements. Likewise, philosophers and artists have referred to architecture as "frozen music," emphasizing the similarities between the order and rhythm of buildings and musical compositions. In this context, music and architecture interact both sensorially and structurally, shaping human artistic and spatial perception. In De Architectura, an essential work on architectural theory from antiquity to the present, Vitruvius states in the chapter On the Education of the Architect;

"The architect must not only be knowledgeable in the theory of canon and mathematics but also have an understanding of music to correctly tune ballistae, catapults, and scorpiones to the appropriate pitch... An architect cannot be a musician like Aristoxenus, yet should not be entirely ignorant of music either" (Vitruvius, 1999).

The conceptual relationships between architecture and music have been influenced by the mathematical ideas of Pythagoras and Plato, and from the Renaissance onward, they have been examined both theoretically and practically (Fig. 1). Antoniades (1990) argues that the arrangement of columns and spaces in Greek temples follows the principles of musical harmony, emphasizing that this correlation is not coincidental. Similarly, Georgiades highlights that the harmony between visual and acoustic perception fosters an aesthetic appreciation. During the same period, Alberti incorporated harmonious musical proportions into his architectural works, an approach that has continued to be embraced by architects and composers in the modern era.

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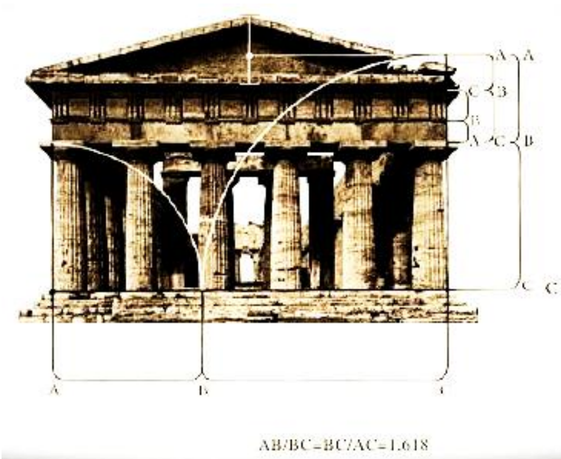

Fig. 1. The Temple of Neptune, Italy, and the Golden Ratio.

Throughout history, the Golden Ratio and the Fibonacci series have served as essential tools in establishing the connection between beauty and mathematical order in art and architecture (Fig. 2). Bartók was among the first composers to systematically integrate these proportions into his music. Similarly, just as Vitruvius argued that the human body should be structured according to arithmetic and geometric measurements, Le Corbusier considered the human scale as a fundamental element of architectural design (İzgi, 1999).

The Philips Pavilion, as one of the pioneering structures where architecture and music converge, embodies the concept of "frozen music." Unlike previous examples, it integrated advanced mathematics and specially composed music to incorporate the third dimension into architectural design, strongly reflecting the relationship between sound and space. Designed for the 1958 Brussels World's Fair on behalf of Philips, this structure was realized through the collaboration of Le Corbusier, the renowned Greek composer and architect Iannis Xenakis, and Edgar Varèse (Fig. 3). While Le Corbusier conceptualized the project, Xenakis developed its innovative structural design, and Varèse provided its acoustic identity through his spatial composition Poème Électronique. Reflecting Le Corbusier's modernist approach, the pavilion combined rational forms and free curves, generating complex surfaces that challenged the architectural terminology of its time. Xenakis, through mathematical calculations, developed these forms, making the Philips Pavilion a unique example of the fusion between architecture and music (Xenakis, 1958). His proposal to Le Corbusier was to conceive an architectural design inspired by his own musical composition Metastasis, emphasizing an interdisciplinary creation process (Leopold, 2003). Xenakis worked on translating the glissando[2] transitions in his composition into architectural form, employing visualization techniques that relied on abstraction and mathematical calculations.

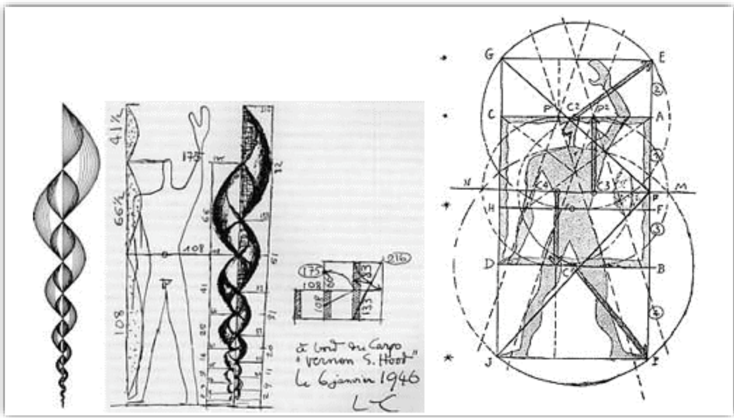

Fig. 2. Le Corbusier and Le Modulor (Url-1)

[2] The term "glissando" in music refers to a gradual transition along a scale, moving either from high to low or from low to high in pitch.

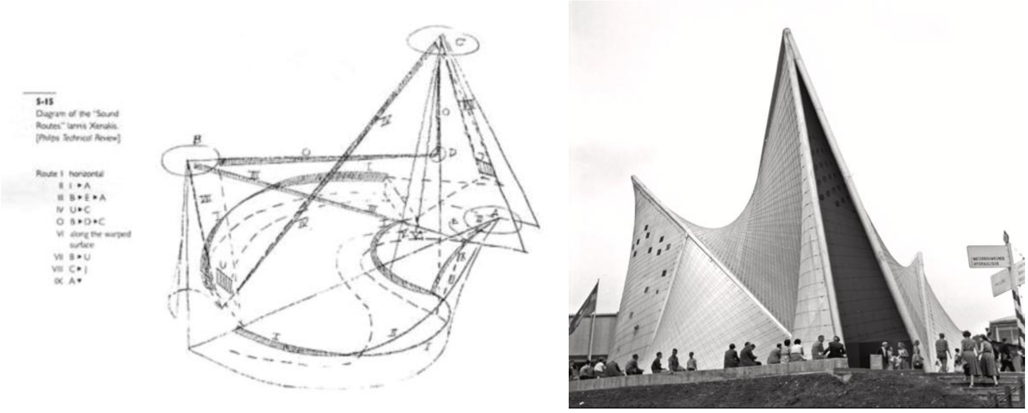

Fig. 3. The music broadcasting diagram designed for the Philips Pavilion (Treib, 1996).

Just as in the Philips Pavilion, Xenakis demonstrated the harmonious integration of architecture, music, and mathematics in both his individual projects and significant collaborations with Le Corbusier, such as La Tourette Monastery (Fig. 4). In La Tourette, the interplay between solid elements (such as walls) and voids (such as windows and doors), along with contrasting light and dark surfaces created through material variations, generates a rhythmic flow. Xenakis's innovative musical notation system not only influenced 20th-century architecture but also reinforced the high rhythmic order in Le Corbusier's projects through his knowledge of geometric proportions (Matossian, 1986).

Designed by Steven Holl, Stretto House was constructed using concrete blocks and distinctive metal curves. Holl is an architect who draws inspiration from music in his designs, and the name of this house is derived from the musical term "Stretto." Stretto in fugue music refers to the overlapping of the main theme as it transitions closely between different voices. Holl applies this principle to architecture by creating an interconnected, overlapping, and fluid design. The integration of the floor with the upper level, the merging of the roof with the walls, and the use of slanted walls to direct natural light inside exemplify this design approach (Fig. 5).

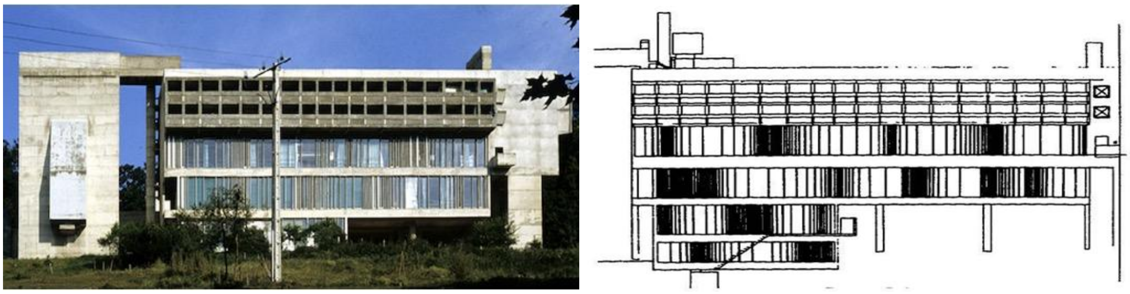

Fig. 4. The undulating 'musical' representation of the glass designed by Xenakis using Le Corbusier's Modulor system (Matossian, 1986).

Fig. 5. Holl's Stretto House (Url-2)

Holl's inspiration for the Stretto House was Béla Bartók's Music for Strings, Percussion, and Celeste. This musical structure was directly integrated into the house's design. For instance, the four masonry walls were based on the second cello's recurring main theme at the end of the composition. Additionally, Holl selected building materials according to the tonal characteristics of the instruments: the light and delicate sounds of the string instruments were represented by glass-enclosed metal roofs, while the heavy and deep tones of percussion were embodied in masonry walls (Fig. 6, Fig. 7). Through this approach, Holl successfully translated the balance of sounds in music into architecture, creating a unique and innovative design.

2. The relationship between music and architecture

Throughout history, architecture and music have been examined from various perspectives and interconnected in multiple ways. The interaction between these two disciplines can be analysed in terms of their functional, philosophical, perceptual, and creative dimensions.

2.1. The functional relationship between music and architecture

The necessity of performing musical activities in dedicated spaces establishes a functional and interactive link between music and architecture. Various architectural structures have been designed specifically for musical performances across different historical periods. Hypostyle halls in Egyptian temples, odea in ancient Rome, Greek arenas, medieval cathedrals for church music, and 18th-century aristocratic salons were all specialized spaces designed for different musical performances. During the 18th and 19th centuries, composers were significantly influenced by the acoustic properties of the venues where they repeatedly performed. For instance, Bach's compositions were shaped by the reverberation characteristics of Thomaskirche Church, where he served as the principal musician. Similarly, the acoustic properties of St. Mark's Basilica in Venice contributed to the emergence of polychoral concert styles, inspiring Giovanni Gabrieli to compose works specifically tailored to this space (Fig. 8).

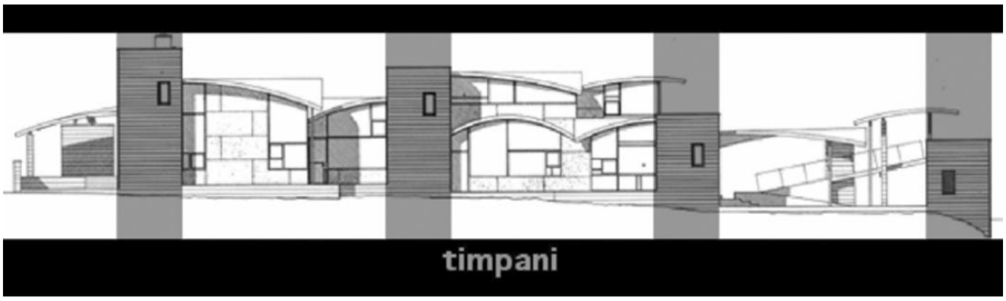

Fig. 6. Extracts from the multimedia analysis of Holl's Stretto House. Heavy elements – orthogonal brick walls – kettledrums (Capanna, 2009).

Fig. 7. Extracts from the multimedia analysis of Holl's Stretto House. Light elements – metallic roofs – violins (Capanna, 2009).

 

Fig. 8. Saint Thomas Church and Saint Mark's Basilica

2.2. The philosophical relationship between music and architecture

Numerous philosophers and architects have drawn metaphorical parallels between music and architecture through various analogies and interpretations. The philosopher F. W. Schelling's definition of architecture has been a source of inspiration for many thinkers. Schelling described architecture as "solidified music", while Schopenhauer referred to it as "frozen music" (Sack, 1997). Similarly, Goethe characterized architecture as "silent music", and Victor Hugo, in his novel, described Notre Dame Cathedral in Paris as "a grand symphony in stone" (Antoniades, 1990) (Fig. 9).

Schopenhauer likened a solid wall in a building to a monotonous sound, while comparing columns arranged at regular intervals to a scale played in an even rhythm. Similarly, Beltcher associated the heavy and imposing walls of a prison with the largo sections of musical compositions and the dynamic facades of Gothic architecture with vivace sections. Such metaphorical connections between architecture and music have persisted through modern and postmodern periods. For example, Daniel Libeskind, who is also a professional accordion virtuoso, seeks order within poetic complexity in his works (Fig. 10). In this context, he frequently establishes non-representational symbolic relationships with music. One of the most notable examples is the Jewish Museum, where he constructs a symbolic bridge between music and architecture. The museum embodies a sense of absence and invisibility, referencing the Holocaust. The concept of void and non-existence is metaphorically linked to Arnold Schönberg's opera Moses und Aron, particularly in its final section, "Der Erinnerungsraum" (Memory Void), where Moses remains silent for an extended period, creating an echo of emptiness (Libeskind, 1992).

 

Fig. 9. Milan Cathedral and Notre Dame Cathedral

Fig. 10. Jewish Museum Berlin (Url-3).

By considering Arnold Schönberg's innovative approach to music as a form of enlightenment, Daniel Libeskind integrated this perspective into his architectural approach, distancing space from traditional typological concepts and conceiving it as a void rather than a structure. This approach illustrates that Libeskind conceptualizes the building as an instrument, highlighting its function by generating resonance through the void. In this way, he transforms the creative process, shifting the museum beyond a conventional exhibition space into a memorial that embodies the spirit of its era (Libeskind, 2008). In his design for the Jewish Museum, Libeskind did not merely use music as a metaphor to shape architectural forms, nor did he directly translate fundamental musical elements such as intervals, rhythm, or meter into architecture. Instead, he explored the relationship between music and architecture by capturing moments of musical incompleteness. Libeskind engaged with the unfinished final section of Schönberg's composition, attempting to complete its absence through architectural expression and thus reinterpreting the boundaries of music within an architectural context (Franck, 2004).

Among architects who translate musical inspiration into tangible architecture, Erich Mendelsohn and Daniel Libeskind stand out as figures who employ music as an architectural paradigm, yet in vastly different ways. While Mendelsohn translated the emotions evoked by music into architecture, Libeskind established a connection with music through a highly intellectual and rational perspective (Franck, 2004). The modernist architect Erich Mendelsohn, known for his expressionist formalism, exemplified this approach in the Einstein Tower, where he employed a musical metaphor to articulate his architectural vision. He likened horizontal architectural elements to melody, while vertical elements represented chords (Fig. 11). In Mendelsohn's view, every architectural structure is akin to a musical composition performed visually.

The fundamental characteristic of music lies in the fluidity of tones and the structuring of its performance technique. The beginning, climax, and conclusion of a musical composition share similarities with Mendelsohn's architectural perspective, which emphasizes a dynamic progression of space. Mendelsohn associated architectural elements with music, emphasizing the principles of harmony and counterpoint. The foundation of this similarity lies in his perception of architecture as an organic whole, where individual elements interweave seamlessly. According to Mendelsohn, harmony can be applied along both horizontal and vertical axes. This approach represents the direct translation of musical harmony and melody into architecture. Rather than considering the concept of time as a third dimension, this reflection—depicted through horizontal and vertical axes in a two-dimensional plane—integrates the notion of melody within a two-dimensional framework.

Fig. 11. Einstein Tower, Germany (Url-4).

2.3. The perceptual relationship between music and architecture

The perception of music through listening and architecture through sight occurs on specific planes that can be simultaneously apprehended. While architecture takes shape in space, music exists within time. A musical composition is an auditory phenomenon, whereas an architectural structure is a visual one. However, in both art forms, aesthetic perception shares common aspects in both the design process and the evaluation of completed works. Before they are performed or constructed, both music and architecture exist merely as potential aesthetic objects. Architecture attains the quality of a real aesthetic object when it becomes tangible in space, while music does so when it becomes auditory. At this point, a distinct parallel emerges between the ways in which these two art forms are perceived.

According to Murray, the perception of music through listening and architecture through sight can be experienced on three fundamental levels:

Sensory Perception – Music is often enjoyed unconsciously, as most people engage with it casually in daily life. Similarly, architecture provides a sensory experience, particularly in Baroque and eclectic architectural styles, where form is shaped predominantly by aesthetic concerns.

Semantic Perception – This level establishes a deeper connection between music and architecture. Music, as an abstract art form, is highly effective in conveying meaningful forms. An essential aspect of the perception of meaning is repetition. While a constantly repeated melody may bore the listener, music that exhibits variation tends to sustain interest. Similarly, architectural structures that repetitively convey the same message tend to lose their appeal over time.

Technical Perception – In music, this involves notes, rhythm, harmony, timbre, and structural composition, while in architecture, it relates to material selection, construction techniques, and functional planning. In both fields, technical elements serve as the foundation for ensuring both aesthetic appeal and functional integrity (Pasin, 2007).

2.4. The creative relationship between music and architecture

The architectural creation process fundamentally consists of analysis, concept development, and synthesis stages. Considering these stages, the striking similarities emerge between the architect and the composer. Some artists experience their inspiration spontaneously and instinctively. Composers like Mozart perceive their musical compositions in a holistic form mentally before transcribing them onto paper, envisioning music as a painting or sculpture. On the other hand, some artists meticulously develop and structure a musical or architectural idea within a specific thematic framework. While Beethoven shaped his music through meticulous refinement and prolonged effort, Mies van der Rohe adopted a similar approach, translating his ideas into architecture through logic, aesthetics, and imagination, using modern materials such as steel and glass. From a traditionalist perspective, Johann Sebastian Bach's music aligns with the architectural expressions of his time, reflecting the era's sophisticated formal structures. Similarly, Ictinus, who composed music inspired by ancient Greek works such as the Parthenon, was also influenced by the artistic sensibilities of his time. However, the art world has always been shaped by pioneers who break away from tradition and embrace innovative approaches. In the 17th century, Berlioz, and in the 20th century, Debussy and Schönberg introduced radical transformations in music, while in architecture, Brunelleschi and Le Corbusier similarly challenged traditional paradigms, developing distinct and original design approaches. In this context, the relationship between music and architecture shares numerous commonalities in terms of the creative process.

3. Conclusions

The examples examined in this study demonstrate that music and architecture share similar design principles and that both disciplines integrate aesthetic, mathematical, and perceptual components. As interconnected fields, music and architecture contribute to the enhancement of artistic perception and the enrichment of spatial experiences. Considering architecture not merely as a visual art but as a multi-sensory, temporal and spatial discipline perceived through all senses will contribute to the development of innovative approaches in design processes. In this context, integrating music into architectural education and utilizing it as an analytical tool in design can be regarded as an effective method for stimulating creative thinking.

According to Robert Morgan, "although music possesses a temporal dimension of perception that is entirely independent of space, space remains an integral part of the musical experience" (Mitchell, 1980). Numerous studies have highlighted the impact of music on architectural design and how music, as a historical and artistic phenomenon, has influenced the evolution of architecture over time. This study has explored the ways in which musical principles resonate within architectural design processes and examines how music functions as a generative force in spatial composition. By analysing historical influences, theoretical frameworks, and practical applications, it has underscored the interdisciplinary relationship between music and architecture. Specifically, this study investigated the impact of musical structures, rhythms, and harmonies on spatial organization and architectural expression, demonstrating how these elements inform and shape the design process.

The influence of music on architecture, through various modes of interpretation and perception, plays a significant role in shaping and developing an individual's architectural style. The ability to analyse a musical composition conceptually, theoretically, structurally, and in terms of its patterns defines a contributory force to architectural composition. Approaching architecture not solely through visual perception but by engaging all sensory perceptions can lead designers to new and innovative design possibilities.

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Evaluation of wood material awareness in architectural education

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Abstract. Wood stands out as a sustainable building material due to its carbon sequestration capacity, recyclability, biodegradability, and renewability. With advancing technology, industrial wood products have improved strength compared to natural wood, along with enhanced resistance to moisture and fire. These developments have made it possible to construct multi-storey and wide-span buildings using wood. Considering these advantages, the use of industrial wood contributes significantly to ecological sustainability in construction. Therefore, it is important for future architects, who play a key role in material selection, to be aware of wood materials and construction systems. This study evaluates the knowledge and awareness levels of architecture students from Karadeniz Technical University, Recep Tayyip Erdoğan University, and Atatürk University regarding wooden building design and industrial wood materials. A questionnaire was conducted to assess the extent of related course content in their undergraduate education and the students' familiarity with these topics. Based on the survey results, the level of recognition of wood materials within the existing curriculum was identified.
Professionals in the construction sector have a responsibility to support ecological balance through sustainable material choices. In this context, the study aims to contribute to the development of environmental awareness among architecture students by emphasizing wood materials at the undergraduate level. It is expected that this awareness will encourage environmentally conscious material decisions in their future professional practice.

Keywords: Wooden buildings; Wooden construction systems; Industrial wood materials

1. Introduction

The materials used in the building sector have many negative impacts on the environment from the production process to the end of their life cycle due to resource consumption, energy-intensive production processes, greenhouse gas emissions and waste generation.

Global warming and climate change, among the major global environmental problems, are caused by excessive carbon dioxide emissions (Švajlenka & Pošiváková, 2023), which jeopardizes the sustainability of the ecosystem. One of the three main goals set within the scope of the "Sustainable Development Goals" adopted by the United Nations in 2015 is the fight against climate change. All sectors have various responsibilities in achieving these goals. According to 2023 emission data, 34% of carbon dioxide emissions originate from the construction sector (United Nations Environment Programme (UNEP), 2025). This ratio shows that production in the construction sector generates high levels of emissions and that the sector has a great responsibility in this area. Available data reveals that it is imperative to take effective measures to reduce carbon dioxide emissions (Demir et al., 2024). Investigations using life cycle assessment methods specific to building materials show that wood-based buildings have 81-94% lower global warming potential compared to concrete buildings and 76-91% lower global warming potential compared to steel buildings (Wang et al., 2024).

Wood, one of the forest products, is a renewable resource (Falk, 2010), as well as a carbon absorber (carbon sink) by sequestering and storing carbon (Iordan et al., 2018). Being a lightweight material that is easy to process and transport, it allows maintenance, repair and modifications to be made easily (Cabeza et al., 2021). Wooden structural elements can be connected to each other by means of interlocking systems, joined or glued with screws, nails, bolts and metal elements. In addition, the detachable nature of the joint connections enables the reuse of wooden elements through disassembly (Çalışkan et al., 2019).

Wood, which has been the most common building material throughout history, has experienced a significant decline in its usage rate with the development of reinforced concrete and steel building systems after the industrial revolution (Çelik et al., 2022). Among the reasons for this situation are the limited cross-sectional dimensions of wood and its lower durability compared to other building materials (Çelik et al., 2022). Growth variations and

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internal defects can affect the strength of wood (Tonyalı et al., 2025). On the other hand, thanks to technological developments, the properties of existing building materials are being improved and new biodegradable building materials are being developed. In this direction, natural wood is transformed into materials with higher mechanical and physical properties by undergoing various processes in the industrial environment. Thus, it has become possible to produce higher and wider-span buildings using wooden construction. In buildings constructed with industrial wood products, waste generation is minimized thanks to prefabricated elements, and environmental pollution such as noise and dust are reduced with advantages such as ease of assembly and shortened construction site time. In addition, the low thermal conductivity of wood (Abed et al., 2022). increases the energy efficiency of buildings and reduces their environmental impact.

In this framework, material selection plays a critical role in reducing the environmental impact of buildings. In order to preserve the natural balance, it is of great importance to choose sustainable building materials. It is within the scope of their responsibilities to protect the ecological balance for experts working in the building sector to choose sustainable materials. At this point, the adequacy of the course contents of architecture and civil engineering departments, which guide the selection of materials and train experts in the sector, is also important. Within the scope of this study, the courses taken by the students of Karadeniz Technical University, Recep Tayyip Erdoğan University and Atatürk University Department of Architecture on wooden building design and traditional and industrial wooden materials during their undergraduate education and their knowledge-awareness levels on this subject were evaluated by questionnaire method. In line with the data obtained from the questionnaire study, the level of recognition of wood material in the current curriculum was determined. This study is expected to, which aims to create awareness from the perspective of wood materials during undergraduate education, will contribute to the students to make material selection with environmental sensitivity in their professional lives.

2. Wooden materials

Wood is a renewable raw material and an easy-to-process natural building material, provided that it is used in a controlled manner (Hegger et al., 2022; Güzel & Yesügey, 2015). It has high heat storage capacity and low thermal conductivity. Being a flexible and lightweight material makes wood a durable option against lateral forces such as earthquakes (Tandoğan Kibar& Aykan, 2024). It also has the ability to store carbon (Tupenaite et al., 2021) and is biodegradable without creating waste in nature. End-of-life wood materials can be reused, recycled as energy and raw materials, or decomposed without harming the environment (Türkeri, 2021). Although wood is a flammable material, it delays the burning of the interior parts by forming a layer of embers from the outside to the inside during combustion and maintains its carrier for a while (Türer, & İzol, 2024). This feature makes wood advantageous in terms of fire resistance.

The use of wood in traditional architecture is generally concentrated in regions with large forested areas. Geographical conditions, climate, cultural needs and local material resources have been effective in the distribution of wooden structures. It is seen that traditional wooden architecture is widespread in countries such as Norway, Sweden, Finland, Canada, USA, Turkey, China, Japan and Korea (Tandoğan Kibar & Aykan, 2024).

Traditional timber construction systems in Turkey are mainly composed of timber masonry and timber frame systems (Fig. 1). The timber masonry system is constructed with wooden elements arranged horizontally on a stone foundation or masonry floor. Connections are provided by "karaboğaz", "kurtboğaz" and "çalmaboğaz" techniques. In the timber-framed system, a stone wall is built up to the flood level, wooden posts and beams are placed on top of it, and the space between the posts is filled with local materials such as mudbricks, stones and bricks. The structures formed with this construction technique are called "hımış structures" (Tandoğan Kibar& Aykan, 2024).


Fig. 1. Timber masonry and timber frame system (Meyveli Köyü Camii, 2025; Yalçın et al., 2022)

Wood material is hydroscopic; it can expand, swell or contract depending on temperature and humidity changes (Hegger et al., 2022; Akkan Çavdar & Lakot Alemdağ, 2024). Natural wood is susceptible to risks such as fungal growth and insect damage. For this reason, more resistant wood species such as cedar and cypress have been preferred in traditional architecture against these problems (Oymael, 2018; Akkan Çavdar & Lakot Alemdağ, 2024). In addition, the limited size of trees made it difficult to pass through large openings (Alkan, 2024). Because of technological developments, industrial wood products with increased strength and expanded dimensional limits have been developed to overcome the disadvantages of natural wood (Alkan, 2024; Yaygır & Korkmaz, 2022). Industrial wood has made it possible to construct wide-span and high-rise buildings, which has increased the use of industrial wood by providing flexibility in design.

Industrial wood products shorten the construction site time, facilitate assembly works and minimize environmental impacts by reducing energy consumption during the construction process thanks to prefabricated elements (Alkan, 2024). These products are produced by combining wood parts such as timber, chips, boards, fiber and sawdust with adhesives and binding agents, impregnation and pressing (Tandoğan Kibar& Aykan, 2024; Avlar & Ustaoğlu, 2017). The main industrial wood products are as follows: Glued Laminated Timber (GLULAM), Cross Laminated Timber (CLT), Nail Laminated Timber (NLT), Dowel Laminated Timber (DLT), Structural Composite Lumber (SCL), Laminated Veneer Lumber (LVL), Parallel Strand Lumber (PSL), Oriented Strand Lumber (OSL), Laminated Strand Lumber (LSL) and Timber Concrete Composite (TCC) (Tandoğan Kibar& Aykan, 2024; Avlar & Ustaoğlu, 2017).

Along with industrial timber, panel systems, cell systems, mixed timber systems and hybrid construction systems have been developed (Tandoğan Kibar& Aykan, 2024). These systems have enabled high-rise timber building designs around the world. For example, the Mjøstårnet building in Norway, built in 2019, has 18 floors and a height of 85.4 meters. The structural system of the building is a hybrid construction system consisting of wood and reinforced concrete (Fig. 2). Reinforced concrete slabs are used in the last seven floors of the building to control the sway caused by the increasing height. The columns and beams of the building are constructed with GLT, the shaft wall is constructed with CLT panels and the floors are constructed with LVL and reinforced concrete ("Mjøstårnet The Tower of Lake Mjøsa", 2025; "World's tallest wooden building. Mjøsa Tower by Voll Arkitekter", 2025 ; Şanlı, 2020). Fire retardant coatings were applied to the wooden elements; firewalls were created and designed to be resistant to fire for 90 minutes (Arıcı, 2024). Mjøstårnet is a mixed-use building serving residential, office and hotel functions ("Mjøstårnet The Tower of Lake Mjøsa", 2025; "World's tallest wooden building. Mjøsa Tower by Voll Arkitekter", 2025; Şanlı, 2020).

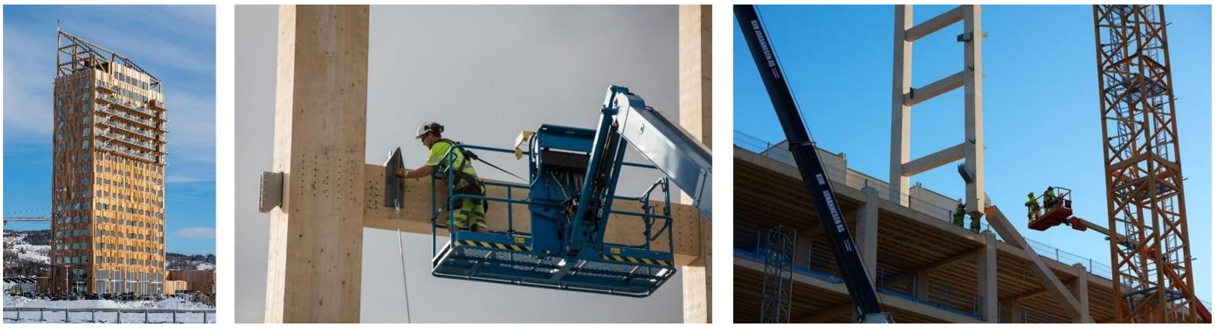

Fig. 2. Mjøsa Tower ("World's Tallest Timber Tower to Be Built in Norway—Thanks to New Rules on What Defines a "Timber Building"", 2025; "World's tallest wooden building. Mjøsa Tower by Voll Arkitekter", 2025)

Ascent Tower, built in 2022, is the tallest wooden structure in the world with its 25-story structure. With 19 floors of timber and 6 floors of reinforced concrete, the building has a hybrid structural system with GLT columns, CLT panels and reinforced concrete cores. For fire safety, measures have been taken to provide 3 hours fire resistance to columns and 2 hours fire resistance to fasteners. The building is equipped with a sprinkler system; a pressurization system was installed in the stairs and corridors to ensure smoke control during fire ("Ascent", 2025) (Fig. 3).

Fig. 3. Ascent Tower ("Ascent", 2022)

In addition to examples of high-rise timber buildings, scientific studies also reveal the critical role of timber in sustainable construction in terms of energy consumption and carbon emissions, as well as its environmental advantages. In a study by Börjesson and Gustavsson, it was revealed that timber framed buildings consume 60-80% less energy in material production than concrete framed buildings (Börjesson & Gustavsson, 2000). In another study, it was stated that if the Stadthous building in London, which was built with CLT in 2009, was constructed in reinforced concrete, 125 tons of carbon emissions could be emitted to the atmosphere ("The Stadthaus", 2025). The findings on energy consumption and carbon emissions in these studies also support the preference of wood as a sustainable building material. In order to meet the need for sustainable construction, there is a need for building sector experts who are effective in the preference of wood building material to be conscious and knowledgeable in this regard.

More effective use of timber in the building sector is possible not only due to its environmental benefits, but also by implementing it within the framework of appropriate engineering standards. In this context, there are various standards and legal regulations regarding timber construction techniques in Türkiye. The standards and regulations for timber building design in Türkiye are as follows: TS 647 "Calculation and Construction Rules for Timber Structures", TS EN 1912 "Construction Timber - Strength Classes - Classification of Tree Species and Visual Classes", TS EN 1995-1-1 "Design of Timber Structures (Eurocode 5)" and "Regulation on the Design, Calculation and Construction Principles of Timber Buildings" which entered into force in 2025.

3. Materials and methods

3.1. Research model

This study is a descriptive field research that aims to evaluate the level of knowledge and awareness of architecture undergraduate students about wood materials, traditional and industrial wood construction systems. The research was conducted within the framework of a mixed research model in which quantitative and qualitative data collection methods were used together. In this direction, a questionnaire form containing structured and semi-structured questions was developed as a data collection tool.

The questionnaire consists of three sections. The first section includes demographic questions that inquire about the participants' gender, age, university of study, grade level and taking courses on wood materials. The second section includes multiple-choice and 5-point Likert-type scale questions that aim to measure the level of knowledge and attitudes about wood construction systems and industrial wood materials. In the third section, there are open-ended questions aimed at revealing students' opinions, comments and conceptual perceptions on the subject in more depth. The answers given to the open-ended questions were evaluated both thematically through content analysis and by visualizing them with the word cloud technique. In this way, students' mental representations and prominent key concepts were analyzed in a qualitative context.

3.2. Sample of the study

The sample of the study consists of 3rd and 4th year undergraduate students studying in the Architecture Departments of Karadeniz Technical University (KTU), Recep Tayyip Erdoğan University (RTEU) and Atatürk University (ATAUNI). The main reason for selecting these class groups is the assumption that students have acquired basic knowledge about timber building systems through courses such as building knowledge, building elements, building technologies and building materials that they have taken in the first years of undergraduate education. Fig. 4 shows the flow diagram of the research methodology.

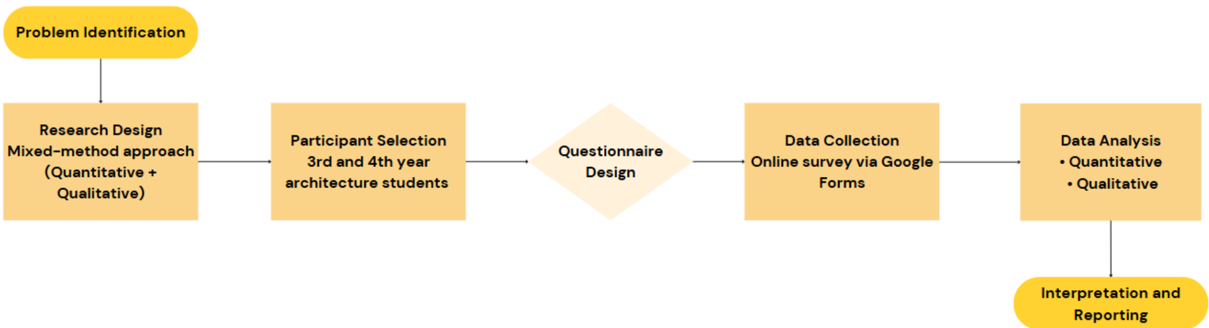

Fig. 4. Research methodology - flowchart steps

Purposive sampling method was adopted in the selection of participants and data were collected online (Google Forms) on a voluntary basis. The survey questions were approved by RTEU Social and Human Sciences Ethics Committee with the decision dated 12.03.2025 and numbered 2025/093. The survey was conducted in the spring semester of 2025 and the total number of participants from the three universities was determined to meet the target sample size. After the number of 3rd and 4th grade students of the three selected universities was obtained from the YÖK Atlas data, a calculation was made by taking into account the 95% confidence level and 5% margin of error in determining the number of samples, and a total of 203 students were surveyed. The research data were analyzed using the SPSS program; descriptive statistics were presented in terms of frequency, percentage and mean values. In addition, the data obtained from open-ended questions were supported and interpreted with qualitative analysis techniques.

4. Findings

In the questionnaires conducted within the scope of the study, the answers given to 5-point Likert-type and multiple-choice questions aiming to measure the level of knowledge and attitudes of students on wood construction systems and industrial wood materials were evaluated and the results are as follows.

66% female and 34% male students contributed to the survey study. 56.1% of the participants were 18-22 years old, 41.9% were 23-27 years old and 2% were 28 years old and above. The sample of the study consisted of students from Karadeniz Technical University with 62.6% (127 people), Recep Tayyip Erdoğan University with 3.4% (7 people) and Atatürk University with 34% (69 people). 52.2% of the participants were third year students and 47.8% were fourth year students. 63.1% of the students stated that they took courses on wood materials and wood construction systems. Among these courses, the most common courses are building materials with 31.3%, building project with 11.44% and building elements with 11.44%.

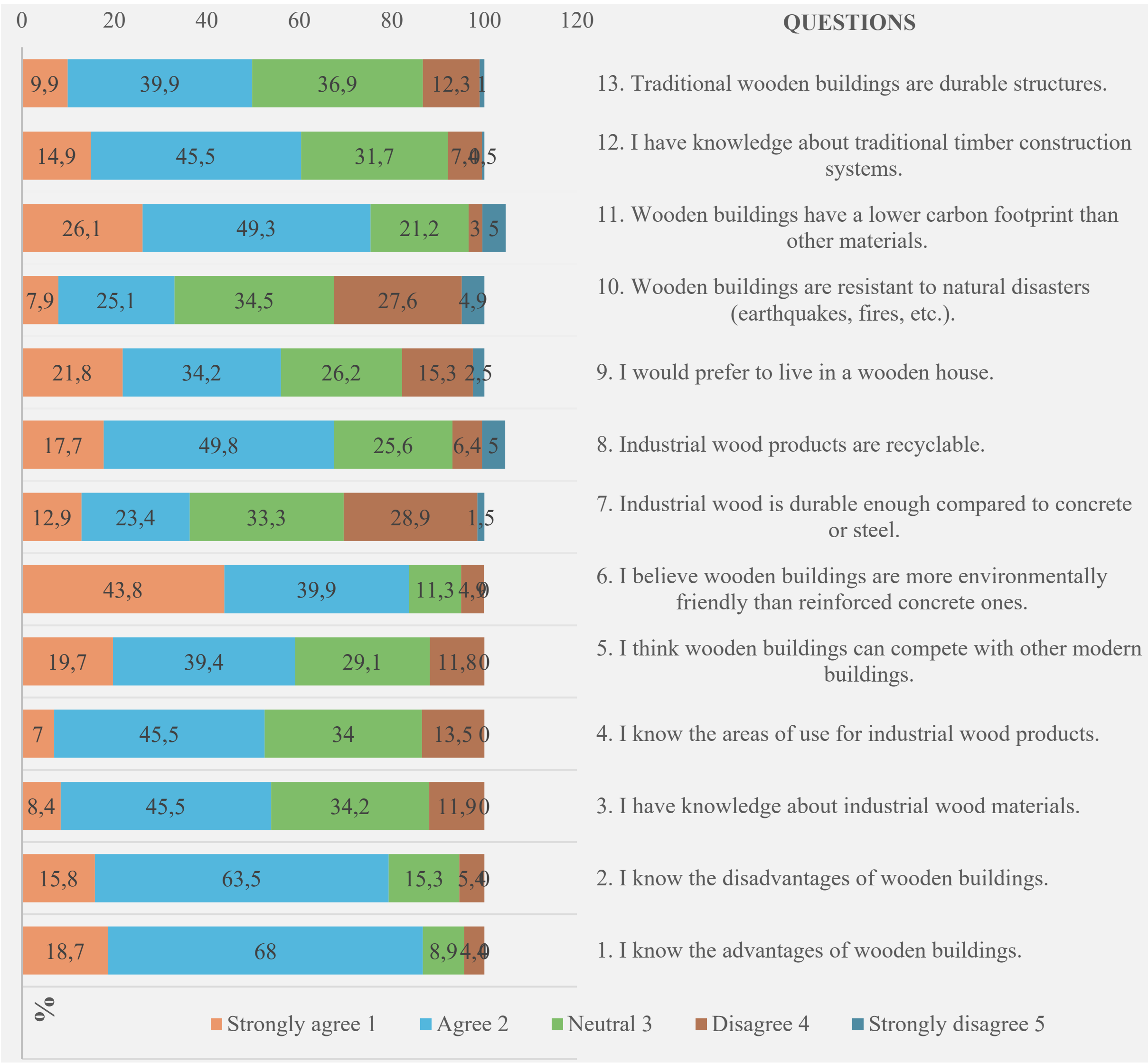

Fig. 5. Distribution of responses to likert-scale questions

When the students' answers to the 5-point Likert questions are analyzed through the graph in Fig. 5, it is seen that the students have a high awareness of the advantages of wooden structures. While 68% of the students stated that they had knowledge about the advantages of wooden structures, 18.7% stated that they were quite knowledgeable. While 8.9% of the participants were undecided about this question, only 4.4% of the participants stated that they had no knowledge. These results show that students generally have a positive and confident attitude towards the benefits of wooden structures. When the level of knowledge about the disadvantages of wooden structures is evaluated, 63.5% of the students stated that they have knowledge about this issue, while 15.8% stated that they have a strong knowledge. This indicates a positive opinion rate of 79.3%. However, a 15.3% rate of indecision indicates that some students are uncertain about the disadvantages.

According to the survey data, a strong consensus was obtained that wooden structures are more environmentally friendly than reinforced concrete structures. While 43.8% of the students completely agreed with this view, 39.9% partially agreed. Only 4.9% of the students expressed a dissenting opinion. Regarding the durability of industrial wood, 12.9% of the participants stated that it was very durable, 23.4% stated that it was durable, while a group of 33.3% students remained undecided. The fact that 28.9% of the group expressed the opposite opinion to this question shows that students have doubts about the durability of industrial wood.

Awareness that industrial wood products can be recycled was found to be generally positive. While 49.8% of the participants stated that they were informed about this issue, 17.7% strongly agreed. However, 25.6% were undecided and 6.4% disagreed, indicating the need for more education on this issue.

The rate of those who preferred to live in a wooden house was 56%, while 26.2% were undecided and 17.8% expressed the opposite opinion. This shows that although there is a general interest in wooden houses, some students are undecided about this issue. In the question that wooden structures are resistant to natural disasters, only 7.9% of the participants stated that they were quite sure about this issue, while 25.1% stated that they partially agreed. The undecided rate of 34.5% and the opposing opinion rate of 27.6% reveal that students lack knowledge on this issue. The view that wooden structures have a lower carbon footprint than other materials is generally supported. While 49.3% agreed with this view, 26.1% strongly agreed.

When the level of knowledge about traditional wooden building systems is analyzed, 14.9% of the participants stated that they were quite knowledgeable, while 45.5% stated that they were knowledgeable. However, an undecided rate of 31.7% and an opposing opinion rate of 7.9% indicate that students need more information on this subject. When the opinions on the durability of traditional wooden structures were analyzed, 39.9% of the participants stated that they were durable, while 9.9% stated that they were very durable. The fact that 36.9% of the students remained undecided on this question and 13.3% of the students expressed the opposite opinion reveals that students need to learn more about this issue. When the answers given in general are evaluated, it is understood that students have a high awareness of the advantages and environmental benefits of wooden structures, but they need more information on technical issues, especially in areas such as durability and resistance to disasters. In this context, it is thought that the content of education on topics such as industrial wood products and traditional building systems should be strengthened.

In the second part of the questionnaire, 10 multiple choice questions were asked to measure students' knowledge and opinions on the use of wood materials, construction systems and industrial wood products. The answers to the questions reveal the level of awareness of the students on the subject. Looking at the opinions of the participants regarding the reasons for the preference of wooden structures, it is seen that the answer "sustainability and environmental friendliness" stands out with a rate of 36.34%. This shows that students prioritize environmental factors in the selection of building materials and are aware of the ecological advantages of wood (Fig. 6).

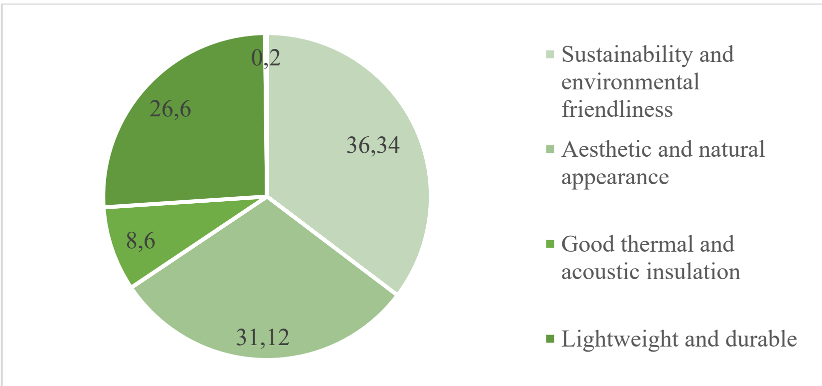

Fig. 6. Reasons for preference of wooden structures

In the responses to the question about the lifespan of wooden structures, 47.3% of the participants foresee a lifespan between 30 and 50 years. This rate shows that students have a realistic and technically based perception of the durability of wood. When the level of knowledge about the proportion of wooden buildings in Turkey is questioned, it is noteworthy that the majority of the participants chose the “no idea” option. This finding indicates that students lack knowledge about the building stock and the rate of use of building materials.

When asked why timber structures are less preferred in Turkiye, cultural habits were cited by 26.5%, perception of fire risk by 25.6% and lack of engineering knowledge and regulations by 17.21%. This distribution shows that in addition to technical inadequacies, social perceptions are also decisive (Fig. 7).

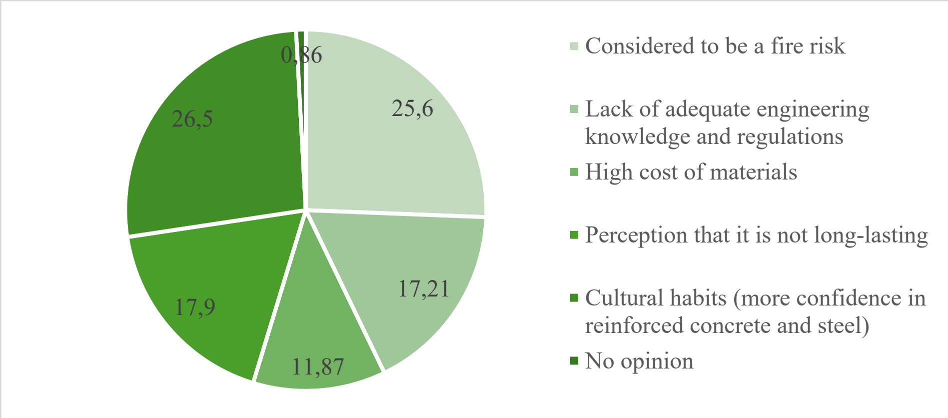

Fig. 7. Reasons for low preference of timber structure in Türkiye

When the answers to the question of which factors play an important role for the proliferation of high-rise wooden buildings in Turkey are evaluated, the options such as the development of fire-resistant materials with 21.7%, raising public awareness with 21.6% and regulations and legislative arrangements with 19.55% come to the fore. These results indicate that both technical and social factors should be addressed together.
In the question measuring the level of knowledge about traditional timber construction systems, 37.26% of the participants stated that they knew the timber frame system, 34.16% the masonry timber construction system and 16.35% the infilled timber frame construction system. These rates show that the building systems emphasized more in the training are better known. In the question asking which system is more advantageous when traditional and modern construction systems are compared, 65,02% of the participants stated that both systems are advantageous in different areas. This approach shows that students are able to make technical evaluations in a holistic manner.

When the answers to the question measuring the level of knowledge about industrial wood materials were evaluated, MDF with 18.64%, laminated wood with 18.54% and plywood with 17.74% were the most known products. This finding shows that students are more familiar with the products they encounter in daily life, while more technical products (CLT, PSL, LVL, etc.) should be covered more in the education process (Fig. 8).

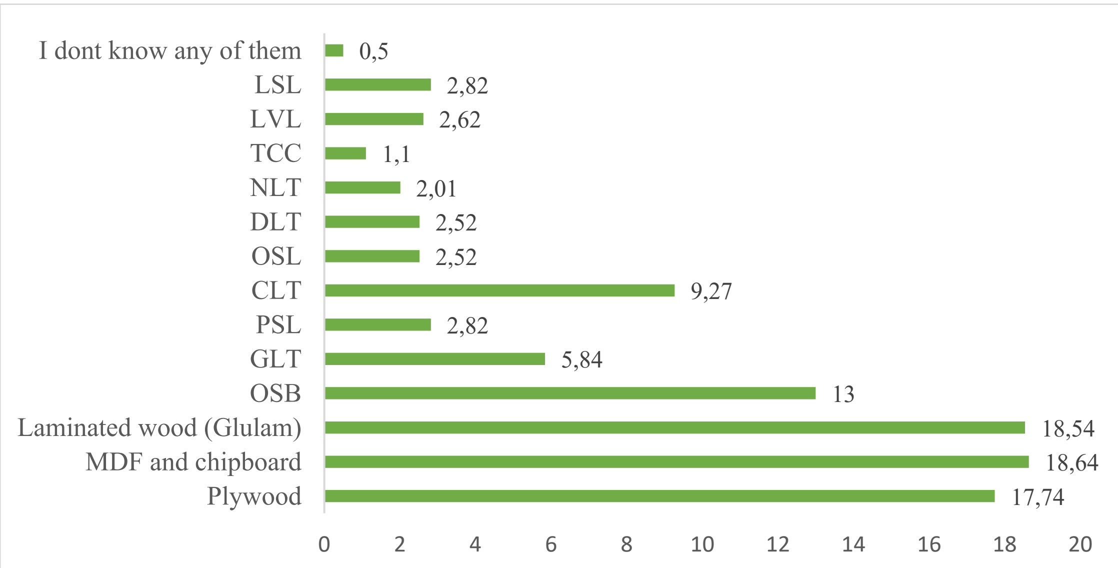

Fig. 8. Recognition of industrial wood materials

The answers given to the question measuring the purpose for which industrial wood material is used in the construction sector were “furniture and interior design” with 13.78%, “facade cladding” with 12.89% and “roof systems” with 12.65%. This result shows that students are more familiar with aesthetic and architectural uses, while technical areas such as structural systems are less known.

Wooden structures have an important place in a wide range from architecture to the construction sector. In the last part of the survey conducted in this context, 3 open-ended questions were asked to determine the first three concepts that came to the minds of the participants about the concept of “Wooden Structures”. In line with the answers given to the questions posed to the participants, various concepts came to the fore. The word cloud images obtained from these concepts are shown in Fig. 9, 10, 11. In the first question, the first three words that the participants associated with the concept of “wooden structures” were; Naturalness (21.8%), Sustainability (12.6%) and Aesthetics (11.9%). These findings emphasize the harmony of wooden structures with nature, their environmentally friendly features and their visual appeal. Wood, as a material known for its naturalness, is preferred because it is in harmony with the constructed structures and keeps its environmental impacts to a minimum.

Fig. 9. Word cloud about wooden structures

In the second question, the first three words that the participants associated with the concept of 'Industrial Wood Material' were MDF (17.13%), OSB (11.9%) and Plywood (10.9%) respectively (Fig. 10). Industrial wood materials are the leading processed wood products used in the modern building sector. Respondents' preference for products such as MDF, OSB and plywood reflects the advantages of these materials such as strength, durability and workability. Such materials are widely used in modern construction as they offer functional solutions. However, words such as “biomaterial” or “wood composite” are less likely to come to mind in relation to industrial wood materials, which may be due to respondents being less familiar with these more technical and emerging concepts. These words require more awareness of new trends and innovative technologies in the sector.

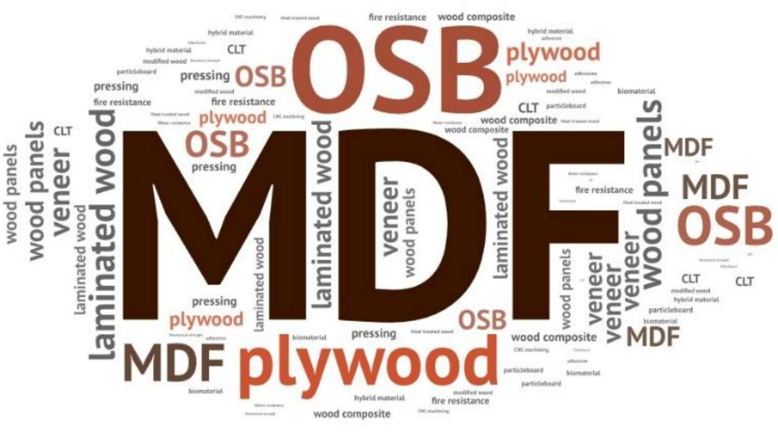

Fig. 10. Word cloud about industrial wood material

Fig.11. Word cloud about traditional wood material

In the third question, the first three words that the participants associated with 'Traditional Wood Materials' were Oak (17.4%), Craftsmanship (12.1%) and Pine (10.2%) (Fig. 11). Traditional wood materials have an important place in historical and cultural contexts. These materials are associated with natural and solid wood species, often shaped by the handcraftsmanship of local craftsmen. Durable wood species such as oak and pine are also among the basic materials for long-lasting and aesthetically valuable buildings. Respondents' high rates of traditional wood species such as oak and pine indicate a strong association with the durability and aesthetic value of these species. The prominence of handcraftsmanship is a reflection of the importance given to fine workmanship and details, which are characteristic of traditional wooden structures.

5. Conclusions

This study aims to evaluate awareness of wood materials in undergraduate architectural education by examining the role of sustainable building materials particularly wood in reducing the environmental impacts of the construction sector. Considering that 34% of carbon dioxide emissions are attributed to this sector, the significance of wood as a renewable material with a low carbon footprint becomes increasingly important. Wood stands out due to its environmental advantages, such as carbon sequestration, ease of processing, recyclability, and energy efficiency. Technological advancements have made it possible to construct high-rise and wide-span structures using industrial wood products.

In this context, the knowledge and awareness levels of third- and fourth-year students from the architecture departments of Karadeniz Technical University, Recep Tayyip Erdoğan University, and Atatürk University were evaluated through a survey. The results, based on responses from 203 students, indicated that while students generally hold positive attitudes toward the environmental benefits of wooden structures, they lack sufficient knowledge about industrial wood products and traditional construction techniques. Students tend to associate the concept of wooden structures with naturalness, sustainability, and aesthetics, and they are more familiar with products such as MDF, OSB, and plywood. However, the education provided regarding the technical advantages of wooden structures, their resistance to natural disasters, and lifespan appears to be inadequate. This is primarily due to the limited coverage of wood-related content in general courses like building science or construction materials.

Therefore, it is recommended that compulsory and elective courses specifically focusing on wood materials and construction systems be introduced or expanded within undergraduate architecture programs. Moreover, incorporating site visits, hands-on examinations of industry examples and materials, and more frequent technical seminars would help enhance students' practical knowledge and support environmentally conscious material selection in their professional practice. This study serves as a pilot research conducted in three universities; thus, broader and comparative research is needed across undergraduate architecture curricula throughout Turkey. Furthermore, since courses on wood materials and construction systems are predominantly offered at the graduate level, this implies that the topic is reserved for specialization. However, as not all graduates pursue postgraduate education, integrating these subjects into undergraduate programs is essential to ensure all future architects gain a fundamental understanding.

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The role of material passports in the integration of building materials with circularity strategies

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Abstract. In the construction sector, the inability to track the stock and flow of materials due to rapid population growth and urbanization brings environmental, economic and social impacts. In order to mitigate these impacts, the importance of transitioning from linear economy to circular economy (CE) strategies in the construction sector becomes clear. Material passports (MP) are considered to be a potential tool for this transition. Material passports are a design optimization tool that reduces the use of primary materials by controlling the stock and flow of building materials. It includes data sets created to facilitate the integration of building materials into their next function by recycling and reusing them. In this study, it is aimed to examine the research on material passport in the construction sector and to evaluate its impact on circularity. The impact of material passports on circularity in the design, construction, operation-maintenance and end-of-life phases of buildings is discussed. In this context, research questions were identified and a systematic literature review was conducted in the Scopus database. The publications accessed as a result of the search were analyzed by addressing the research questions. In the findings, the potentials and challenges of material passports in the specified life cycle stages of the building were identified and their impact on the circularity of building materials was evaluated. It is envisaged that this research is important in terms of material passport analysis in the construction sector and will contribute to future studies.

Keywords: Building materials; Material Passports; Material stock and flow; Circularity; Reuse and recycle

1. Introduction

Since the Industrial Revolution, the rapidly growing global economy has brought about environmental crises. Increased consumption of non-renewable resources, a decrease in the amount of primary raw materials, and uncontrolled waste production threaten ecosystems (Cossu et al., 2015). One of the sectors at the center of these environmental crises is the construction sector. Rising urbanization rates, housing demand, and infrastructure needs driven by population changes are accelerating construction activities and creating environmental impacts. According to the United Nations Department of Economic and Social Affairs (UN-DESA), the world population is projected to reach 9.7 billion by 2050; this population increase means increased demand for materials and energy for the construction sector (UN-DESA, 2024; Lieder & Rashid, 2016). In addition to the demand for materials and energy, challenges are being faced in waste management. It is stated that the construction sector is responsible for 50% of total raw material consumption, approximately 40% of total energy consumption, and 38% of waste production in Europe (WGBC, 2022; Hu et al., 2025; Eurostat, 2024). In this context, ensuring the management of construction and demolition waste and reducing raw material consumption have become important. Additionally, the increase in carbon emissions alongside these issues in the sector has become critical. Globally, the construction sector accounts for approximately 37% of carbon emissions (UNEP, 2023). These data highlight the environmental responsibilities of the construction sector and bring with them the need for transformation.

The construction sector operates based on the traditional linear economic model of "take-make-dispose." This model creates a production cycle that increases resource consumption and carbon emissions, leading to uncontrolled waste generation (Frosch & Gallopoulos, 1989). In this context, the need for a new approach that addresses the entire life cycle of buildings has come to the forefront. The concepts of "circularity" and "circular economy" form the basis of this new approach. Awareness of environmental issues increased in the 1970s, and studies on this subject began. The United Nations Conference on the Human Environment (Stockholm Conference) in 1972, the establishment of the World Commission on Environment and Development in 1983, the publication of the Brundtland Report in 1987, the Rio Conference in 1992, the Kyoto Protocol in 1997, the Paris Agreement in 2016, and the European Green Deal in 2019 were realized.

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It is stated that the concepts of "circularity" and "circular economy" are based on the "cradle to cradle" approach, which was drafted by Walter R. Stahel in the 1970s and developed by Michael Braungart and Bill McDonough (EMF, 2023). Circularity was transformed into a strategy in the European Green Deal of 2019; its importance increased with the "New Circular Economy Action Plan" adopted by the European Commission in 2015 and published in 2020 (European Commission, 2020; Ma et al., 2023). Along with this action plan, the aim is to reduce the negative environmental impacts caused by various sectors, including the construction sector.

The circular economy is a model that enables the value chain to operate at maximum efficiency by keeping resources within the system for as long as possible and returning waste to its source (Papamichael et al., 2023). In the construction sector, the approach of keeping materials within a closed loop is prevalent. The construction sector has been categorized under "Key Product Value Chains" in a report published by the European Commission, emphasizing the need to rethink the built environment (European Commission, 2020). In the construction sector, the adoption of circularity strategies has become a priority not only in the production of new buildings but also in the reuse and recycling of existing building materials.

Although there is no clear definition of the concept of circular economy, the 3R (reduce, reuse, recycle) strategies are commonly used (Purchase et al., 2021). These strategies are at the forefront of reducing environmental problems through the efficient use of natural resources. More detailed research has identified the "10R" strategies (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover) as a general guideline (Potting et al., 2017). It is anticipated that circular strategies will have a significant positive impact in the construction sector. This new model is thought to support environmental, economic, and social sustainability in contrast to the shortcomings of the linear economy model. The reuse and recycling of construction materials and the reduction of raw material consumption create an efficient system. However, there are certain challenges in integrating circularity strategies into the construction sector. Many different actors are involved in the life cycle of buildings, and supply chains are complex (Pomponi & Moncaster, 2017). In this context, controlling building material flows becomes difficult. Circular approaches require that materials used in the built environment be safe and accessible. As a solution to these challenges, digital databases have come to the forefront. Digital systems support the conversion of existing building stock into raw materials, the tracking of material flows, and the evaluation of buildings as material banks (Heisel & Rau-Oberhuber, 2020; Honic et al., 2019a). In this bank system, buildings are not only considered for their lifespan but also as a potential resource for future constructions. One of the most prominent tools used in treating buildings as material banks is "Material Passports (MP)".

Material passports are digital-based systematic datasets that include the technical properties, environmental impacts, and reuse and recycling potential of a building material or element (Honic et al., 2024). These passports give materials and elements an identity, transforming them into recyclable assets. Thanks to material passports, the recycling and reuse status of a building can be analyzed at every stage of its life cycle. These circularity tools enabled by digital transformation are increasingly integrated into BIM (Building Information Modeling)-based systems, facilitating the traceability and management of building components (Atta et al., 2021). With the Material Passport, product characteristics can be transferred to new users. This system, which creates digital twins of building components, facilitates information sharing among stakeholders, bringing all stakeholders from designers to demolition contractors together on a common platform.

MP applications have gained popularity in Europe with the "Buildings As Material Banks (BAMB)" project. This project is an initiative carried out in 2015 by 7 countries and 15 partners within the scope of the Horizon 2020 project funded by the EU to facilitate the transition to a circular built environment (Debacker & Manshoven, 2016; BAMB, 2025). BAMB provides a digital platform for collecting, storing, and using building data. According to the BAMB project's approach, materials are temporarily stored in buildings and can be reused in the long term (Leising & Bocken, 2018). The project utilizes various tools, with the material passport platform being one of them. The material passport platform contains comprehensive data sets on material information, recycling and reuse potential, health and safety data, usage history, environmental impact data, assembly and disassembly, etc. (Heinrich & Lang, 2019). Madaster, a similar application to BAMB, is based in the Netherlands and is used in many countries, including Germany and Switzerland (Madaster, 2022). Madaster archives material data in a digital format and converts it into passports, supporting circular strategies (Costa & Hoolahan, 2024). Users can view the material flows, lifespan, carbon footprint, and reuse and recycling status of building components. The MP system enables data transfer from BIM models (Heisel & Rau-Oberhuber, 2020). In addition to these platforms, software such as ÖKOBAUDAT, SundaHus, and One Click LCA have also been developed. Since 2019, with the increasing importance of circularity, studies have been conducted on the contributions that material passports can make to the circularity of building materials. However, in addition to these contributions, there are also challenges and obstacles in MP applications.

This study highlights the importance of circular strategies and digitalization in addressing environmental issues such as increasing energy consumption, resource depletion, carbon emissions, and waste production in the construction sector. Within this scope, the concept of Material Passports, developed to support the circularity of construction materials, is discussed; the aim is to identify the potential offered by these digital tools and the challenges encountered in their implementation.

In the study, a systematic literature review was conducted using the Scopus database. A general overview was provided by referencing studies related to construction materials, circularity, and the circular economy. For the analysis of publications related to Material Passports, quantitative data analysis was conducted by including relevant keywords. As a result of this phased analysis, it was determined that the proportion of publications related to material passports is low. The data obtained in both phases were visualized using VOSviewer software. After the preliminary screening process, the publications were filtered according to their relevance through full paper analysis. The relevant publications were analyzed in detail to identify the potential and challenges that emerge in the integration of material passports into circularity. This study is significant in that it systematically evaluates the role of material passports in the circularity of construction materials in the literature, and it is anticipated that the findings will contribute to future studies.

2. Methodology

There are many studies and publications in the construction sector focusing on the circularity of construction materials. This study examined how many of these publications included material passports and the challenges and potential for their implementation. After providing detailed literature information on the concepts, a search was conducted in the Scopus database using general terms ("building materials," "circularity," and "circular economy"). It was determined that studies gained momentum following the presentation of the European Green Deal in 2019. Publications from 2019 to 2025 and those in English were referenced in the search. As a result of this filtering, a total of 831 publications were identified. To determine how many of these publications included material passports, the same filtering steps were used, including the concept of "material passports." The search of the database revealed 17 publications. This value indicates that material passports need to be studied more in the construction sector. The results of the two-stage search were visualized in VOSviewer software to produce a network map and clusters. The 17 publications were analyzed by reviewing their abstracts and full papers. One full paper could not be accessed and was excluded; nine publications were observed not to directly focus on potential and challenges. The purpose, scope, methods, and findings of the seven publications selected through the screening process were examined. The findings were categorized from environmental, economic, political, technological, social, and technical perspectives. The research flowchart is presented in Fig. 1. The study, which evaluates the potential and challenges of material passports, a digital tool, using publications, was based on the following research questions:

- RQ1: What is the number of publications examining the circularity of building materials and what are the prominent concepts?
- RQ2: What is the number of publications examining the circularity of building materials and material passports and what are the prominent concepts?
- RQ3: Which of the publications examining material passports address potentials and challenges?
- RQ4: What are the potentials and challenges in integrating material passports to circularity?

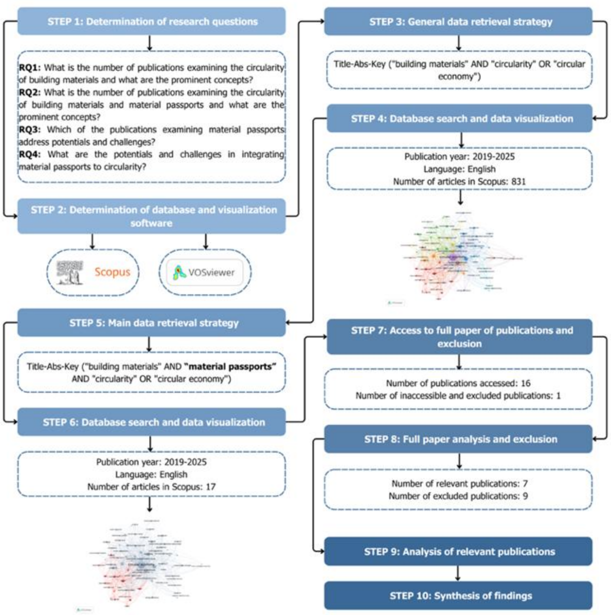

Fig. 1. Flow chart of the study

3. Findings

As a result of the search conducted using the terms “building materials,” “circularity,” and “circular economy,” 831 publications were visualized using VOSviewer software. Co-occurrence and keywords were examined in this analysis. A total of 82 keywords and 8 clusters were identified. The circularity of building materials and the circular economy are studied in many different fields and in connection with each other. The keywords that stand out in the cluster analysis are shown in Fig. 2. Node sizes indicate how frequently the concepts are studied. Cluster 1 (indicated in red in the figure) contains the concept “material passport” and related keywords. In this cluster, the concepts of reuse, recycle, waste, demolition, deconstruction, disassembly, BIM, LCA (Life Cycle Assessment), and End-of-Life (EoL) stand out. It is known that the use of material passports in the construction sector is directly related to these concepts.

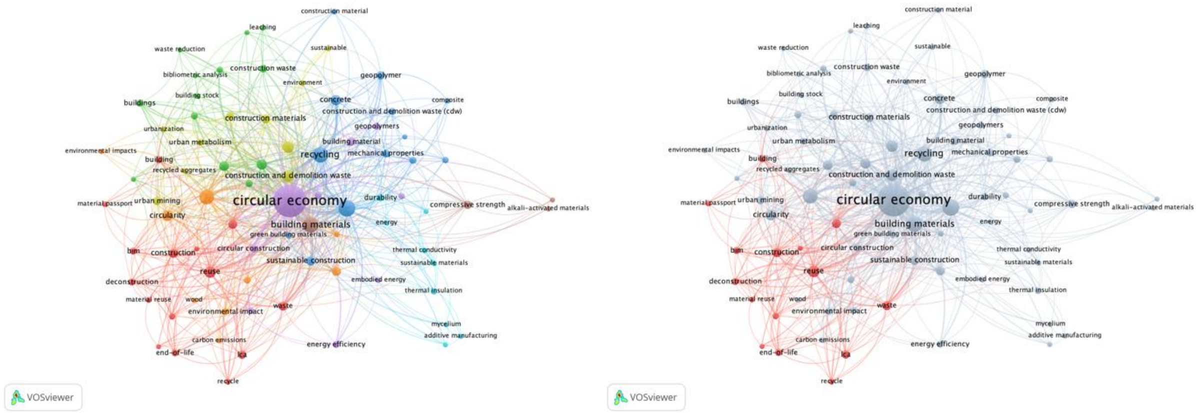

Fig. 2. Cluster and network analysis with VOSviewer software

As a result of the search customized with the concept of material passport, 17 publications were accessed from the 831 publications obtained. These publications focus on 7 publications as a result of abstract and full paper analysis. These publications include the difficulties and potentials in the application of material passports. The authors, titles, years, author keywords, and document types of the identified publications are listed in Table 1. The publications were analyzed in detail, focusing on their objectives, scope, methods, and findings.

Table 1. Information on the studies examined within the scope of the research

Authors	Title	Year	Author Keywords	Document Type
Honic M., Kovacic I., Sibenik G., Rechberger H.	Data and stakeholder management framework for the implementation of BIM-based material passports	2019	Building Information Modelling; Data and Stakeholder Management; Material Passport; Recycling; Resources Efficiency	Article
Munaro M.R., Fischer A.C., Azevedo N.C., Tavares S.F.	Proposal of a building material passport and its application feasibility to the wood frame constructive system in Brazil	2019	Building Material Passport; Wood Frame; Circular Economy; Bank of Materials; Built Environment	Conference paper
Kovacic I., Honic M., Sreckovic M.	Digital platform for circular economy in AEC industry	2020	BIM; Eco-Indicators; Material Passport; Modeling; Resources; Urban Mining	Article
Munaro M.R., Tavares S.F.	Materials passport's review: Challenges and opportunities toward a circular economy building sector	2021	Circular Economy; Construction Sector; Materials Passport; Reuse and Recycling	Article
Göswein V., Carvalho S., Cerqueira C., Lorena A.	Circular material passports for buildings - Providing a robust methodology for promoting circular buildings	2022	Building; Circularity; Level(s) Framework; Material Passport	Conference paper
Abuhalimeh D., Shahin A., Elenany Y., Beheiry S.	Material passports for the End-of-Life stage of buildings: A systematic review of benefits & challenges	2023	Building Construction; Circular Economy; Construction & Demolition Waste Management; End-of-Life; Material Passports; Material Re-Use	Conference paper
Andisheh K.	Development of steel circularity passport: Literature review, research gaps, and program rules in New Zealand	2024	Building; Circular Economy; Circularity; Material Passport; Reuse; Steel	Article

Honic et al. (2019b), propose a BIM-based semi-automatic MP methodology to assess the recycling potential of building materials according to circular economy strategies. Based on the research project titled “BIMaterial-Process Design for a BIM-based Material Passport” and tested on an office building, it was determined that 48% of the materials are recyclable. Additionally, challenges related to data gaps and stakeholder coordination were identified. These challenges include inconsistent naming in databases, unit differences, and stakeholders lacking sufficient knowledge on the subject. In this context, a multi-dimensional data and stakeholder management framework aimed at enhancing collaboration between Architecture, Engineering, and Construction (AEC) organizations, industry, and regulatory bodies has been developed. In conclusion, the study demonstrates that BIM-based semi-automatic MP can be created, that MP implementation in the construction sector relies on collaboration among stakeholders, and that passports are an effective digital tool for achieving circularity goals.

Munaro et al. (2019), propose a building material passport (BMP) model specific to timber frame building systems in Brazil and assess its applicability within a circular economy framework. The study defines the eight main components of the BMP (general data, security, sustainability, use and operation, disassembly guide, reuse, history, other information) and tests the model using technical documents from a company in Brazil. The results showed that data for the main components of sustainability, disassembly guide, and reuse were missing. This situation hinders the implementation of circular strategies and makes it difficult to evaluate the system based on the material bank concept. These challenges have been identified from political, commercial, and social perspectives. The study emphasizes the importance of encouraging the adaptation of BMP to wooden frames in Brazil and implementing the necessary regulations.

Kovacic et al. (2020), evaluate the potential of digital technologies to achieve circular economy goals in the AEC sector in a research project-based study. In this context, the study proposes an integrated digital model called DEEP (Digital Platform for Circular Economy). A case study was conducted at a planning company using the research projects "BIMaterial (Process-Design for a BIM-based Material Passport)" and "SCI_BIM (Scanning and data capturing for the Integrated Resources and Energy Assessment using Building Information Modeling)." The findings indicate that BIM has the potential to serve as a data management tool that contributes to CE. However, data inconsistencies, lack of standards, and insufficient coordination among stakeholders were identified as challenges. The proposed DEEP platform aims to facilitate data sharing among stakeholders and improve material efficiency by tracking material flows throughout the lifecycle. The study highlights the significant role of digitalization in the renovation of the construction sector.

Munaro and Tavares (2021), through their systematic literature review, aimed to raise awareness by examining the contribution of material passports to circular economy strategies in the construction sector. By reviewing 15 academic publications, the political, commercial, and social barriers to the widespread adoption of material passports, as well as the opportunities they offer, have been identified. The study developed an MP model consisting of nine sections that can be used throughout a building's life cycle. However, numerous challenges hindering the widespread adoption of MP applications in the sector were also addressed. These include the lack of data standardization, complex supply chains, insufficient material information, the absence of quality assurance for recycled materials, the need for continuous updating of MP, inadequate digital infrastructure, and the reluctance of suppliers to share data, among others. The study emphasizes that the MP can be used as a multi-stakeholder and innovative tool to contribute to circularity by implementing the necessary systematic regulations in its application.

Göswein et al. (2022), evaluate the Circular Material Passport (CMP) system, a digital data tool developed to support the transition to circular economy principles in the construction sector, and propose a new model. In this evaluation, relevant sections within the EU Level(s) framework applicable to office and residential buildings were examined. The proposed model evaluates data from three perspectives: "general data," "product context use, and location," and "circularity potential." The study analyzes existing barriers to CMP and examines proposed measures. These barriers include lack of awareness and standardization, data uncertainty, misinterpretation of data, interoperability issues between different scales of passports, oversimplification of material quantities, misleading estimates of building and material lifetime, neglect of structural and insulation materials, and data input fatigue of the user. In conclusion, the research demonstrates that CMPs are a strategic tool that contributes to circularity in the construction sector and provides a methodology to support implementation processes.

Abuhalimeh et al. (2023), systematically analyzed the contribution of material passports to the circular economy. In this study, which examined 37 academic studies conducted between 2015 and 2022, a bibliometric analysis was firstly conducted to determine the direction of the research. In the next phase, the contributions of MP to CE at the end-of-life (EoL) stage were examined. Finally in study, the benefits of implementing MP's were classified in terms of environmental, economic, and social aspects, while the challenges were classified in terms of technical, market, regulatory, political, commercial, and social aspects. When examining the benefits of MP, the following stand out: in environmental terms, the conservation of natural resources, reduction of CO_2 emissions, and reduction of waste; in economic terms, reduction of government spending and development of the second-hand material market; and in social terms, increase in employment and positive effects on human health. The challenges include data deficiencies and inadequate digital infrastructure in the technical field; lack of legal standards in the regulatory field; lack of economic incentives in the market; and conflicting environmental and energy policies at the political level. Based on the analyses, the study argues that there are gaps in the implementation of material passports and that existing barriers could be overcome through further applied research.

Andisheh (2024), focuses on the Steel Circularity Passport (SCP) system developed to facilitate the reuse of structural steel within the circular economy. Through a systematic literature review, Material Passport applications were examined on a global scale, with a particular focus on regulatory, technical, and economic barriers encountered in structural steel in the New Zealand context. The study also explored potential measures that could be taken to facilitate the implementation of the proposed SCP system. The study emphasizes that the SCP is an important element in transitioning New Zealand's steel sector toward a more circular economy.

Based on the studies reviewed, the potential and challenges of integrating material passports into the circularity of construction materials have been identified. These findings have been categorized under environmental, economic, political, technological, social, and technical headings (Table 2).

Table 2. The potential of MP and challenges in implementation

Category	Potentials	Challenges
Environmental	• Increasing material recycling rates • Evaluating materials through reuse • Reducing raw material consumption by using secondary materials • Ensuring waste management during construction demolition and dismantling stages • Reducing energy consumption during life cycle stages • Reducing carbon footprint	• Lack of LCA data • Insufficient data on the existing building stock • Control of material toxicity
Economic	• Reducing material costs • Creating secondary material markets • Reducing construction and demolition costs • Extending the material value chain	• Cost uncertainty due to lack of standards • Underdeveloped market • Storage costs and space constraints • Perceived high cost of establishing a material passport infrastructure
Political	• Infrastructure opportunities compatible with circular economy policies • Ability to integrate with the European Green Deal and certification schemes	• Inconsistencies in measures included in environmental and energy policies • Lack of standards for the use and sale of secondary materials • Lack of a quality assurance system for recycled and reused materials • Inadequacy of government incentives
Technological	• Digitalization with BIM and LCA • Integration with smart buildings and digital twins • Automatic data processing capabilities	• Lack of knowledge about BIM and LCA • Lack of data format standardization • Databases are still developing • High volume of data and digital storage • Difficulty of real-time data updates
Social	• Enhancing trust through transparent data sharing • Increasing user awareness • Creation of new business areas and opportunities • Supporting participatory design processes	• Lack of awareness and incentives • Insufficient stakeholder participation • Lack of applicable and flexible work areas • Low demand for secondary materials • Lack of information and stakeholders' concerns about using second-hand materials
Technical	• Design guidance for demolition and reuse • Infrastructure development for material traceability and analysis	• Complexity of the material supply chain • Lack of knowledge about building materials and components • Lack of data accuracy and consistency • Long-term durability of buildings

4. Conclusions

The construction sector plays a significant role in the emergence of environmental issues such as raw material consumption, energy use, increased carbon emissions, and waste production. In addressing these issues, circular economy strategies, particularly "reduce, reuse, and recycle," are gaining prominence. It is believed that the compatibility of construction materials with circular strategies throughout the building's life cycle is crucial for minimizing environmental impacts. Material passports, developed to support the circularity of construction materials, serve as an important digital optimization tool for this purpose. This tool, which gives building materials an identity, supports circular economy strategies with systematic and accessible information. MP plays an important role in keeping building materials in a closed loop by enabling the tracking of material stock and flow. Although these digital tools hold significant potential, their effective use also brings about various challenges.

This study aims to determine the potential and application difficulties of material passports. A workflow was followed according to the research questions identified. Systematic literature reviews were conducted using the Scopus database. It was determined that there are few studies on building materials, circularity, circular economy, and material passports. The potential and challenges identified in the accessed publications were analyzed in detail. The findings were evaluated according to environmental, economic, political, technological, social, and technical categories. There is a cause-and-effect relationship between the potential and challenges both within the category and across categories. For example, the environmental potentials include "increase material recycling rates," "reduction of material costs," and "infrastructure compatible with circular economy policies." Similarly, the economic challenges include "lack of standards for the use and sale of secondary materials" and "cost uncertainty due to lack of standards." The importance of using material passports in the construction sector can be examined those potentials and challenges to address information gaps and increase usage. Countries may have different positions, policies, and practices in this area; therefore, priorities may vary.

In conclusion, material passports hold significant potential for supporting the circularity of construction materials. However, for MP applications to be realized, environmental, economic, social, political, technical, and technological barriers need to be overcome. It is believed that this process can be achieved through steps such as strengthening regulatory frameworks, fostering collaboration among stakeholders, raising awareness, addressing knowledge gaps, providing government incentives, developing innovative technologies, and promoting market maturity. This study is expected to contribute to future research on the alignment of material passports with the circularity of construction materials.

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Spatial and physical studio configurations: a conceptual model for student satisfaction and efficacy

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Abstract. Studios serve as essential physical learning environments within higher education institutions, fostering experiential and reflective learning practices. They play a critical role in cultivating skills, creativity, collaboration, and professional identity. Although virtual environments offer flexibility and accessibility, physical studios remain fundamental to architectural education due to their pedagogical significance and their embodied, spatial, and interactive dimensions. Focusing on the studio as a physical environment, this study develops a conceptual model that distinguishes spatial and physical characteristics and investigates how the relevant features shape cognitive, emotional, and behavioral responses, which are collectively referred to as human-place interaction dimensions, ultimately influencing student satisfaction and academic performance. Drawing from a narrative literature review of theoretical and empirical studies sourced from academic databases, the proposed model identifies spatial characteristics, such as layout and floor plan, scale and proportions, spatial flexibility and adaptability, circulation and flow, and visual connectivity, alongside physical characteristics, including materials and construction, furniture and workstations, technology and equipment, visual comfort-lighting, thermal comfort, and acoustic comfort. Moreover, the study synthesizes the key features of these characteristics. The conceptual model underscores how targeted, user-oriented studio environments can significantly influence cognitive processes, emotional well-being, and constructive behaviors, ultimately enhancing student engagement, comfort, productivity, and psychological well-being. This research provides a blueprint for architects, and planners aiming to create inclusive, innovative, and pedagogically effective studio environments that foster academic success and creative development.

Keywords: Learning Environment; Architectural Design Studios; Spatial and Physical Characteristics; Student Satisfaction and Efficacy; Conceptual Model

1. Introduction

Learning environment within educational settings is a specific context where individuals engage in teaching and learning activities through various information resources and tools designed to support the accumulation of knowledge and serve educational purposes (Seel, 2012). Fraser (1998) conceptualizes learning environments as perceptual, relational, and context-specific constructs, with a strong emphasis on their psychosocial dimensions as important characteristic. Learning environments should not be seen simply as physical enclosures for activities, but as complex entities that transcend their architectural structure (González-Zamar et al., 2020). A learning environment is not simply a physical setting. It is a dynamic, fluid, and socially-constructed environment, shaped by interactions among people, practices, discourses, and material conditions (Mulcahy et al., 2015). A learning environment refers to the full range of factors that shape how students experience and engage with learning, including contextual elements such as psychological, social, cultural, political, and educational conditions, as well as pedagogical aspects such as curriculum, teaching, and assessment methods (Hounsell & Hounsell, 2007; Cleveland 2009; Abualrub et al., 2013). Radcliffe (2008) defines a learning environment through a conceptual model comprising three components: “Pedagogy, Space, and Technology”. The author emphasizes that all three pillars must be considered when planning, designing, and evaluating such environments.

Learning environments are categorized as either physical, virtual and hybrid, depending on whether learning occurs in a tangible setting or through technology-mediated platforms. Virtual learning environments include distance learning, e-learning, and online learning, though these terms differ. Distance learning involves separation of instructor and learner in time or place and includes various delivery modes. E-learning uses electronic tools and offers interactive, flexible instruction. Online learning is internet-based, involving fully web-delivered content such as courses, webinars, and video lectures (Moore et al., 2011). On the other hand, a physical learning

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environment refers to a tangible setting that includes spatial, material, and technological conditions that support learning objectives (Salomon, 1998), involving face-to-face interaction in settings such as classrooms, seminar and lecture halls, laboratories, and studios. In recent years, the integration of physical and virtual formats has given rise to hybrid learning environments, which combine face-to-face and online pedagogical strategies. The type of learning environment often depends on factors such as the learning objectives, target audience, content type, and the availability and accessibility of resources.

Virtual learning environments offer flexible, personalized, and accessible educational experiences, often enabling collaboration across distances (Al-Fraihat et al., 2019). These beneficial features that make them widely used and preferred learning environment by both institutions and students (Valtonen et al., 2021). However, they also require strong digital literacy skills and may lack the spatial and social dynamics inherent in physical learning settings. Consequently, growing attention has been directed toward the role of physical learning environments in enhancing student engagement and learning outcomes (Vercellotti, 2018).

In higher education institutions, physical learning environments encompass a variety of spaces such as classrooms, seminar rooms, lecture halls, laboratories, and studios. Classrooms are typically enclosed spaces used for interactive or lecture-based teaching, with seating and technology arrangements that support group learning. Seminar rooms are learning spaces intended to promote communication, debate, and interaction, where students are encouraged to engage critically with course content and one another, often under the guidance of a facilitator rather than a lecturer . Lecture halls or lecture theaters (Jamieson et al., 2000) are larger venues designed for formal, instructor-centered presentations, often accommodating large audiences. Laboratories offer hands-on learning environments for disciplines such as science and engineering, where specialized tools and equipment are essential. Studios, on the other hand, are adaptable spaces tailored to design-oriented disciplines.

In architectural education, the design studio serves as the primary physical learning environment, particularly within higher education institutions. Since applied courses form the core of the curriculum, studios are essential for fostering the experiential and reflective processes central to architectural learning (Salama, 2015; Emam & Taha, 2021; Wong, 2023). This pedagogical model closely aligns with Kolb's (1984) experiential learning theory, which builds on Lewin's (1946) foundational work. Widely applied in architectural education, Kolb's model describes learning as an iterative cycle consisting of four stages: "Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation". These stages capture the dynamic qualities that define studio-based learning. Complementing Kolb's framework, Schön (1984) emphasizes the importance of "learning by doing" through activities such as drawing, building, and writing core elements of the studio experience. The author characterizes the studio as a "reflective practicum" where students engage in "reflection-in-action," developing knowledge and insight through the process of design itself. This reflective, practice-based learning mirrors real-world professional practice and supports the development of both creative and disciplinary skills. Dutton (1987, p. 16) further describes architectural studios as "active sites where students are engaged intellectually and socially, shifting between analytic, synthetic, and evaluative models of thinking" across a variety of activities such as drawing, conversing, and model-making. Beyond their educational function, studios often become deeply personal spaces for students. As Oh et al. (2013) note, the studio evolves into a second home a space where students not only work intensively but also socialize, study, and even rest.

The pedagogical value of studio-based learning in architectural education depends on studio spaces that function effectively and support educational goals. To achieve this, a collaborative, needs-driven approach to studio design is essential. It begins by identifying the intended learning outcomes and then shaping the environment to support those objectives (Jamieson et al., 2000; Kokko & Hirsto, 2020). Bamford (2008) highlights the importance of creating learning spaces in higher education that foster both knowledge acquisition and the development of discipline-specific skills, ultimately preparing students for their professional futures. Similarly, learning environments in higher education institutions are increasingly viewed not just as places for transferring knowledge, but as catalysts for critical thinking, creativity, and the formation of professional identity (Mulcahy et al., 2015). Several studies focus on the impacts of physical learning environments in shaping students' satisfaction and academic performance in higher education. Findings consistently emphasize that well-designed spaces that are user-oriented and aligned with intended learning outcomes significantly enhance comfort, focus, and motivation. These qualities contribute to more meaningful engagement with learning activities, promote deeper understanding, and ultimately support academic success (Hill & Epps, 2010; Jin & Peng, 2022; Costa & Steffgen, 2020). Soleimanipirmorad and Vural (2018) highlight that the quality of the physical environment in educational buildings plays a critical role in shaping students' well-being and academic performance. They suggest that when basic environmental factors such as air quality, lighting, acoustics, and spatial organization are inadequate, they can trigger symptoms of "Sick Building Syndrome", leading to physical discomfort, reduced focus, and diminished productivity. Rather than viewing educational spaces purely as architectural forms, the study frames them as functional environments that must support health, comfort, and cognitive efficiency for effective learning to occur. Akimova and Chikeneva (2019) support this idea by emphasizing that an educational environment should minimize risks to students' physical, mental, and social well-being. They highlight the need for environments that support health, safety, and positive development.

A physical learning environment comprises both physical and spatial characteristics, each playing a distinct role in shaping the user experience. The distinction between the two is essential for understanding how places are perceived, experienced, and function. Physical characteristics refer to the tangible, material elements of a space including materials and construction, furniture and workstations, technology and equipment, visual comfort (Lighting), thermal comfort, acoustic comfort which directly affect comfort, usability, and sensory experience. In contrast, spatial characteristics relate to the configuration and organization of the space including layout and floor plan, scale and proportions, spatial flexibility and adaptability, circulation and flow, visual connectivity. These features influence how individuals navigate, interact within, and interpret the environment, ultimately impacting both behavior and learning outcomes.

Building on these discussions, this study aims to differentiate between the physical and spatial characteristics of studios as physical learning environments. It develops a conceptual model that identifies and explains the key features of architectural design studios that influence student satisfaction and academic performance. Specifically, the study addresses the question: What are these characteristics, and how do they enhance student outcomes? By synthesizing theoretical perspectives and empirical findings through a comprehensive literature review, the study proposes a structured framework for evaluating studio environments. This model not only demonstrates how specific design features contribute to learning effectiveness but also offers practical guidance for educators, architects, and institutional planners in creating more inclusive, engaging, and pedagogically supportive studio spaces in architectural education.

2. Method

This study adopts a narrative literature review approach to explore the physical and spatial characteristics of learning environments and their impact on student satisfaction and academic efficacy, with a particular focus on studio-based education in architecture. Relevant literature was collected through targeted searches in reputable academic databases known for high-quality coverage, including Scopus and Web of Science (Burnham, 2006; Guz & Rushchitsky, 2009; Mongeon & Paul-Hus, 2015), along with Google Scholar to ensure a broader inclusion of sources. The initial search employed combinations of keywords such as pedagogical, architectural education, learning environment, physical learning space/environment, and studio, alongside student outcome-related terms including satisfaction, academic performance, efficacy, engagement, and productivity. To deepen the investigation, a second round of searches targeted more specific documents addressing particular aspects of studio configuration, especially those related to spatial characteristics such as layout and floor plan, scale and proportions, spatial flexibility and adaptability, circulation and flow, and visual connectivity and physical characteristics, including materials and construction, furniture and workstations, technology and equipment, lighting, thermal comfort, and acoustic comfort. This dual-phase search strategy ensured both breadth and depth in identifying relevant literature for conceptual model development. The selected studies were analyzed to synthesize both theoretical and empirical insights that inform the development of a conceptual model for the architectural design studio. Table 1 presents keywords used in literature review search.

Table 1. Litreture review keywords query.

Main Category	Subcategory	Keywords
Pedagogical Context	Higher education institution	Architectural Education
Learning Environment	Physical	Studio
User	Student Outcomes	Satisfaction, Academic Performance, Efficacy, Engagement, Productivity
Studio Configuration	Spatial Characteristics	Layout and Floor Plan, Scale and Proportions, Spatial Flexibility and Adaptability, Circulation and Flow, Visual Connectivity
	Physical Characteristics	Materials and Construction, Furniture and Workstations, Technology and Equipment, Visual comfort (Lighting), Thermal Comfort, Acoustic Comfort

3. Theoretical framework

Place is constructed through human-place interaction, which is commonly understood through three interrelated dimensions: behavioral, cognitive, and emotional (Low & Altman, 1992). The behavioral dimension refers to the physical actions and activities individuals perform within a place. The cognitive dimension involves how individuals perceive the place through meanings, beliefs, and knowledge and personal associations with a place.

It encompasses personal interpretations, memories, and mental mapping. The emotional dimension captures the affective responses and attachments individuals develop toward their environment, including feelings of comfort, belonging, and emotional bonds that connect people to specific places. These three dimensions provide a valuable lens for examining the relationship between place and user, particularly in understanding how students engage with studio environments as meaningful places within the context of architectural education (Peng et al., 2022). The spatial characteristics of studio environments play a critical role in shaping students' interactions, interpretations, and emotional responses to their learning space, as spatial qualities are known to influence human behavior (Baldassare, 1978). Layout and floor plan influence behavioral engagement by guiding how students move and act within the studio, while also influencing cognitive dimension through understanding of spatial perception and orientation. Scale and proportions primarily affect the cognitive domain by informing how space is mentally processed and contribute to the emotional dimension by influencing feelings of comfort, enclosure, and psychological well-being. Spatial flexibility and adaptability enable a range of activities, thus supporting behavioral needs, and foster cognitive engagement by encouraging autonomy and creative exploration. Similarly, circulation and flow affect behavioral ease of movement through the space and enhance cognitive clarity regarding spatial organization. Lastly, visual connectivity contributes to cognitive understanding of the spatial structure and promotes emotional well-being by fostering a sense of openness and connection within the environment. The physical characteristics of architectural studios significantly influence students' behavioral, cognitive, and emotional engagement with the learning environment. Materials and construction contribute to the cognitive dimension through their aesthetic and symbolic qualities, while also shaping emotional responses by evoking familiarity and sensory appeal. Furniture and workstations support behavioral interaction by affecting usability, posture, and movement within the space, and also influence both cognitive and emotional dimensions by enhancing comfort and overall satisfaction. Technology and equipment enable students to perform learning tasks, reflecting the behavioral dimension, and promote cognitive engagement through interaction with tools that support design processes. Visual comfort (Lighting) impacts the cognitive dimension by affecting visibility, attention, and task focus, while also shaping the emotional atmosphere of the space through its influence on mood and ambiance. Thermal comfort is primarily associated with the emotional dimension, contributing to physical well-being and overall satisfaction with the studio environment. It also engages the cognitive dimension by influencing concentration and mental alertness, particularly in learning settings that require sustained focus. Similarly, acoustic comfort plays a key role in the emotional experience, affecting stress levels and the sense of tranquility within the space, while also supporting the cognitive dimension by minimizing distractions and facilitating auditory processing and verbal communication. Table 2 illustrates the alignment between studio configuration components and the behavioral, cognitive, and emotional dimensions of human-place interaction.

Table 2. Alignment of studio configuration components with human-place interaction dimensions.

Studio Configuration	Subcategory	Behavioral	Cognitive	Emotional
Spatial Characteristics	Layout and Floor Plan	●	●	
	Scale and Proportions		●	●
	Spatial Flexibility and Adaptability	●	●	
	Circulation and Flow	●	●	
	Visual Connectivity		●	●
Physical Characteristics	Materials and Construction		●	●
	Furniture and Workstations	●	●	
	Technology and Equipment	●	●	
	Visual comfort (Lighting)		●	●
	Thermal Comfort		●	●
	Acoustic Comfort		●	●

4. Spatial characteristics

4.1. Layout and floor plan

The layout and floor plan of an architectural studio's spatial organization are more than matters of convenience; they fundamentally frame students' cognitive and behavioral experiences; subsequently academic performance of students (Omale et al., 2024). Jin and Peng (2022) demonstrated that layout arrangements significantly influence collaboration and perceived comfort, emphasizing that eliminating a fixed front in active-learning environments compared to passive, traditional row-based learning settings enhances these outcomes. Similarly, Abdelbaky et al. (2022) highlighted that centralized and U-shaped layouts were most effective for fostering group interaction, whereas radial and clustered configurations supported individual exploration, underscoring the importance of aligning spatial arrangements with learning activities.

Expanding on the relationship between studio layout and learning effectiveness, Arshard et al. (2023) revealed that narrow aisles and overcrowded layouts suppressed movement, ventilation, and student engagement, while open-plan studios with generous walkways encouraged adaptability and higher participation. Circulation patterns and visual openness were found to significantly impact how comfortably students transitioned between individual critique and collective discussion. Reinforcing these insights, Thoring et al. (2020) argued that open-plan and visually connected settings promote spontaneous encounters that enhance creativity, while flexible zones allow students to reconfigure spaces according to the evolving phases of the design process.

4.2. Scale and proportions

In studio environments, scale and proportion mediate the fit between human bodies, furniture, and enclosure, directly shaping comfort and cognitive ease. Achieving this means supplying each student with sufficient personal area, matching furniture dimensions to anthropometric data, and preserving harmonious spatial ratios throughout the space. Jin and Peng (2022) showed that enlarging personal space from ~0.8 m^2 in passive classrooms to ~2.2 m^2 in active-learning settings markedly increased comfort and spatial satisfaction. Peng et al. (2022) added that generous floor area aids movement but excessive distance can hinder group audibility, underscoring the need for an optimal not maximal scale. Likewise, Arshard et al. (2023) found that cramped desks, low clearances, and mismatched furniture heights caused discomfort and restricted circulation, while Abdelbaky et al. (2022) observed that limited floor space curtailed activity choices. Thoring et al. (2020) further linked a sense of “spaciousness” to freer and creative thinking. Accordingly, providing approximately 2 m^2 per student, aligning furniture and walkways with anthropometric data, and maintaining balanced proportions enhance physical comfort, reduce cognitive noise, and enhance creative engagement; undersized or poorly proportioned spaces undermines these benefits.

4.3. Spatial flexibility and adaptability

Spatial flexibility enables the studio environment to evolve alongside changing pedagogical needs and project phases. Across multiple studies, three key insights emerge: reconfigurable layouts enhance learning, flexible furniture systems promote collaboration and creativity, and adaptability must be paired with active teaching methods to yield real benefits. Jin and Peng (2022) found that movable furniture and modular layouts were the strongest drivers of student satisfaction, allowing learners to tailor the space to their tasks. Similarly, Salama (2015) criticized static, traditional studio models and emphasize emphasized the need for adaptable environments to meet the demands of contemporary education. Abdelbaky et al. (2022) and Arshard et al. (2023) further demonstrated that flexible layouts supported higher engagement and iterative work, while fixed arrangements limited movement and dialogue. Thoring et al. (2020) linked flexible zones to greater psychological freedom, a catalyst for creativity. these findings position spatial flexibility and adaptability as essential for fostering dynamic learning within the architectural studio.

4.4. Circulation and flow

In studio environments, effective circulation determines how easily individuals move through the space, supporting comfort, collaboration, and creativity. Studies highlight three key points: wide, clear walkways promote interaction; narrow or linear ones create congestion and limit participation; and intuitive, easily navigable layouts lower mental effort and sustain focus. Field measurements by Arshard et al. (2023) and observations by Jin and Peng (2022) found that wide walkways facilitated smooth movement and peer interaction, while narrow aisles led to congestion, discomfort, and disrupted activities. Specifically, Arshard et al. (2023) reported that walkways measuring $\geq$ 2.4 meters enabled seamless peer exchange, whereas aisles $\leq$ 1.4 meters caused crowding and task disruption. Similarly, Thoring et al. (2020) and Higuera-Trujillo et al. (2021) emphasized that clear spatial organization and appropriate distances between work zones encourage spontaneous encounters, reduce cognitive load, and enhance positive emotional responses. Taken together, the evidence positions circulation as a critical element in studio design: wide, obstacle-free routes enable dynamic learning and interaction, while cramped, poorly planned paths limit movement, disrupt focus, and hinder collaboration.

4.5. Visual connectivity

In studio environments, visual connectivity plays a crucial role in linking separate zones into a shared, perceptually open space where ideas, feedback, and motivation circulate freely. Studies highlight three main insights: unobstructed sight-lines enhance instructional clarity; open visual links foster peer learning and community; and well-calibrated transparency stimulates creativity without overwhelming individual focus. Jin and Peng (2022) and Peng et al. (2022) demonstrated that movable whiteboards, mobile boards, and distributed screens positioned throughout active-learning spaces improved multi-angle visibility, ensuring all students could access teaching content and participate fully during group activities. Observations by Arshard et al. (2023) showed that open-plan studios, with strategically placed furniture and workstations, allowed students to observe each other's work, encouraging spontaneous critique and informal mentorship a principle also advocated by Salama (2015), who emphasized the importance of transparent, integrated workspaces where students "learn by seeing."Thoring et al. (2020) further reinforced the value of calibrated openness, showing that transparent materials such as glass partitions and layered interior vistas maintained visual connection across zones, stimulating cognitive engagement while preserving focus. Collectively, these findings highlight that the strategic positioning of furniture, boards, and transparent materials is essential for creating a visually connected, collaborative, and creatively charged studio environment.

5. Physical characteristics

5.1. Materials and construction

The materials and construction features of a studio significantly influence its aesthetic quality, safety, and physical comfort. Among these, aesthetic quality plays a critical role in shaping students' experiences. Frazier (1973) emphasizes that thoughtful spatial design enhances students' engagement, sense of comfort, and feeling of belonging, positioning aesthetic experience as a fundamental component of learning environment rather than a decorative addition. The aesthetic quality of a space is largely determined by the choice of materials, colors, and finishes, which together create visual harmony and foster creativity and focus (Cleveland & Fisher, 2014). Natural materials such as wood or stone can evoke a sense of warmth and connection to the environment, creating a more welcoming learning atmosphere. In contrast, modern finishes contribute to a clean, professional aesthetic that supports concentration and productivity. Additionally, the use of vibrant colors, engaging textures, and dynamic patterns can further stimulate learning motivation by making the environment visually stimulating and inviting (Taylor, 2008).

Beyond aesthetics, material and construction features must also address physical comfort including visual, acoustic, thermal, and tactile aspects to create an effective learning environment. While visual comfort (in relation to lighting), acoustic comfort, and thermal comfort are discussed in their respective sections, this part focuses specifically on tactile comfort. The role of materials in shaping tactile comfort is critical, as it directly influences students' physical interaction with the learning space. Surfaces such as desktops, flooring, and furniture finishes significantly affect how comfortable and inviting a space feels. Smooth, soft-touch materials enhance tactile comfort, whereas rough, hard, or cold surfaces can cause physical discomfort and distraction. Regulating surface temperatures through appropriate material choices further contributes to maintaining a pleasant tactile experience. Equally important is ensuring safety through durable material and construction features. Savolainen (2023) emphasizes the significance of a safe physical learning environment, highlighting the role of risk management practices, fire safety compliance, and the prevention of physical hazards through durable and well-maintained facilities. Essential elements include slip-resistant flooring, sturdy furniture, secured fixtures, and non-toxic, fire-resistant materials, all of which are critical to minimizing risks and fostering a secure and supportive learning environment.

5.2. Furniture and workstations

Ensuring the ergonomic and anthropometric suitability of furniture is essential for supporting comfort, focus, and engagement in studio environments (Arshard et al., 2023). Appropriate furniture, particularly generously sized and well-designed drawing tables, is highly valued by architecture students for facilitating daily tasks, creative work, and productive engagement; notably, workspace size was found to significantly impact architecture students' design processes (Nik Bahari Shah et al., 2019). Additionally, movable, adjustable, and ergonomic furniture enhances both physical comfort and psychological well-being, providing spatial autonomy and improving students' overall satisfaction with their learning environment (Jin & Peng, 2022). Providing flexible furniture is essential for supporting diverse group activities and enhancing the adaptability of learning environments. Modular tables enable rapid reconfiguration, facilitating multiple uses and transformable layouts to meet changing pedagogical needs. In addition, mobile chairs with wheels, flexible backs, adjustable seat heights, and adequate foam padding promote both physical comfort and ease of collaboration (Cornell, 2002). Together, these design features contribute to greater student engagement, comfort, and the effectiveness of active learning practices.

5.3. Technology and equipment

Technology and equipment are essential in architecture education studio environments. As Hill and Epps (2010) note, physical learning spaces integrate computer technology, audiovisual systems, projection tools, and communication equipment to support diverse learning styles and enhance instructional delivery. Recent studies highlight that learning environments are evolving to incorporate emerging technologies that enrich the educational experience. Traditional setups, once focused on drafting tables and modeling equipment, have evolved with the integration of advanced tools such as computer-aided design software (CAD), 3D printers, laser cutters, VR platforms, and AI. Wang et al. (2023) emphasize that these technologies transform spaces into immersive, interactive, and personalized learning environments. Kuleva (2024) states that VR-based interventions improve engagement, motivation, and learning efficiency. Lee and Lee (2021) argue that AI personalizes instruction, supports real-time evaluation, and fosters adaptive learning environments. To support these innovations, modern learning studios need to feature multi-display systems, interactive software, and mobile devices, creating flexible spaces that enhance collaboration and engagement (Peng et al., 2022).

5.4. Visual comfort (Lighting)

Lighting is a critical component of the studio environment, affecting visual comfort, cognitive performance, and academic achievement (Samani & Samani, 2012). Both natural and artificial lighting contribute to the overall quality of the space, with key technical factors such as illuminance levels, uniformity, glare control, color temperature, and the color rendering index (CRI) significantly affecting its effectiveness. The EN 12464-1:2021 standard provides guidelines to optimize both comfort and performance. It recommends 500 lux for general tasks and 1000 lux for more detailed work, with a uniformity ratio of 3:1 to prevent visual discomfort. To minimize glare, the UGR should be below 19, while a color temperature of 4000K–5000K is ideal for focus, and 3000K is suited for relaxation areas. A CRI of above 80 ensures accurate color representation, essential for tasks like design and reading. The standard also emphasizes integrating natural daylight to improve comfort and reduce energy consumption, while specific tasks benefit from higher illuminance and cooler lighting.

Research by Zhao et al. (2025) highlights that optimal indoor conditions featuring a high color temperature (4400-4900 K) and medium to high illuminance (500-800 lx) enhance visual comfort, thereby supporting cognitive function. In contrast, Mott et al. (2012) found that focused lighting with high illuminance levels (1000 lux) and a cool color temperature (6500 K) significantly improved reading fluency, suggesting that while balanced lighting supports overall comfort, intense lighting can optimize performance in specific tasks. Ricciardi and Buratti (2018) further emphasized the importance of lighting design, noting that higher illuminance levels can enhance visual comfort, reduce fatigue, and improve concentration, but cautioning that excessive brightness could lead to glare and discomfort. Natural light also plays a crucial role in enhancing students' satisfaction and well-being (Dahlan et al., 2015). Studies have shown that access to daylight improves concentration, cooperation, and reduces symptoms like headaches and fatigue, with architecture students particularly preferring spaces with abundant natural light (Emara et al., 2024). These findings underscore the need to carefully tailor lighting environments to meet educational goals, balancing comfort and performance to enhance student success.

5.5. Thermal comfort

Thermal comfort in studio environments is influenced by several interrelated factors, both physical and personal. Key physical parameters include air temperature, mean radiant temperature, relative humidity, and air velocity, all of which shape students' thermal sensations. Personal factors, such as clothing insulation and metabolic rate, also play an important role in how individuals perceive the indoor climate. Objective indicators, like the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD), are commonly used to assess thermal conditions, while subjective assessments, such as thermal acceptability and preference, provide valuable insights into students' comfort perceptions (Corgnati et al., 2007). According to EN ISO 7730:2005, the recommended air temperature range for educational settings is between 20°C and 26°C, with a mean radiant temperature between 18°C and 26°C. Air velocity should be maintained between 0.1 m/s and 0.2 m/s, and relative humidity should ideally fall between 30% and 60%. To achieve and sustain these optimal indoor conditions, the installation and proper operation of appropriate HVAC (Heating, Ventilation, and Air Conditioning) systems are essential. HVAC systems regulate thermal parameters, ensuring a stable and comfortable environment alongside a metabolic rate of 1.2 met (light work) and clothing insulation of 0.5 to 1.0 clo. Lack of thermal comfort leads to distraction, fatigue, and reduced cognitive ability, whereas optimal thermal conditions support concentration, learning efficiency, and overall well-being in educational settings. Wargocki and Wyon (2013) emphasize that improved thermal and air quality conditions can be cost-effective and beneficial for students, suggesting that enhancing ventilation rates improves student performance by reducing CO_2 levels and boosting air quality. Similarly, Krawczyk and Dębska (2022) found that maintaining classroom temperatures between 22°C and 24°C results in higher student comfort and more efficient work, highlighting the strong link between thermal comfort and academic performance. These studies underscore the importance of thermal comfort, and by extension effective HVAC system implementation, as critical factors influencing both well-being and academic success in educational settings.

5.6. Acoustic comfort

Acoustic comfort is a crucial factor that influences both student satisfaction and academic performance in studio environments. In studio settings, where both individual concentration and collaborative discussions are required, effective management of acoustic comfort is essential for supporting focused work, clear communication, and reducing cognitive fatigue. The activities within a studio environment include individual study, desk critiques, group study, and group critiques, as well as jury critiques all of which require distinct acoustic considerations to maintain comfort and productivity (Ozcevik & Yuksel, 2004). Poor acoustic conditions, such as high noise levels and long reverberation times, can significantly hinder students' learning, concentration, and well-being, while also affecting instructors' vocal health (Zhang et al., 2024). Achieving acoustic comfort in higher education learning environments depends on several factors, including maintaining background noise levels of ≤ 35 dBA, controlling reverberation time based on room volume, and ensuring high speech clarity with a Speech Transmission Index (STI) of ≥ 0.75 (ISO 3382-2:2008). The integration of balanced acoustic materials and properly designed voice amplification systems further contributes to creating learning spaces that support concentration, communication, and student well-being (Duran, Ausiello, & Battaner-Moro, 2019). Additionally, the acoustic properties of materials and the room's geometry, including size, shape, and surface finishes, play a critical role in ensuring a balanced and comfortable auditory environment (Tabatabaei Manesh et al., 2024).

6. Discussion

The spatial and physical characteristics of architectural studio environments are pivotal in shaping students' cognitive, emotional, and behavioral development. A carefully designed studio environment can significantly enhance learning outcomes, student satisfaction, engagement, productivity, and psychological well-being. The key spatial and physical features synthesized through the literature review are presented in Tables 3 and 4, emphasizing the importance of adopting a holistic, user-oriented approach to studio space design.

Table 3. Key Features for the spatial characteristics of studio environments in architecture education.

Spatial Characteristics	Key Features
Layout and floor plan	Clear, open layouts Centralized/U-shaped layouts Radial/clustered layouts
Scale and proportions	Providing approximately 2 m² space per student Furniture dimensions aligned with anthropometric data Balanced spatial proportions Avoid inadequate proximity as well as excessive separation
Spatial flexibility and adaptability	Reconfigurable layouts Flexible zones Adaptable and movable furniture
Circulation and flow	Wide, unobstructed walkways (≥ 2.4 meters) Avoid narrow aisles Intuitive, clear circulation Open paths
Visual connectivity	Unobstructed sight-lines Open visual links Transparent materials (glass partitions, open interior views) Strategic furniture and board placement

Table 4. Key Features for the physical characteristics of studio environments in architecture education.

Physical characteristics	Key Features
Materials and construction	Aesthetic quality (materials, colors, finishes) Tactile comfort (surface temperature, smoothness) Use of natural materials (wood, stone) Safe materials (non-toxic, fire-resistant) Slip-resistant flooring Sturdy furniture and secured fixtures
Furniture and workstations	Ergonomic furniture Adjustable and movable chairs and desks Modular and flexible layouts for group/individual activities Proper sized workstations (drawing tables) Mobile chairs with wheels, adjustable heights, flexible backs Adequate foam padding for comfort

Table 4 continued

Technology and equipment	Integration of computer technology and CAD software Use of 3D printers and laser cutters VR platforms for immersive learning AI tools for personalized instruction Mobile devices and multi-display systems Audiovisual and projection systems
Visual comfort (Lighting)	Balanced use of natural and artificial lighting Illuminance levels: 500 lux (general), 1000 lux (detailed tasks) Uniformity ratio 3:1 Glare control (UGR<19) Color temperature: 4000–5000K (focus), 3000K (relaxation) Color Rendering Index (CRI >80) Integration of daylight to enhance well-being
Thermal comfort	Installation of appropriate HVAC system Air temperature between 20–26°C Mean radiant temperature between 18–26°C Relative humidity between 30–60% Air velocity between 0.1–0.2 m/s
Acoustic comfort	Background noise levels ≤ 35 dBA Short reverberation times adjusted to room volume High speech clarity (STI ≥ 0.75) Balanced use of acoustic materials Proper voice amplification systems Optimized room geometry and surface finishes for acoustics

7. Conclusion

Although virtual learning environments have become increasingly prevalent, physical learning environments such as studios remain fundamental to architectural education, where experiential, spatial, and practice-based learning establish the core of its pedagogical approach. Building on this understanding, this study provides a conceptual model that identifies the spatial and physical characteristics of architectural design studios essential for enhancing student satisfaction and academic efficacy. Grounded in a synthesis of theoretical frameworks and empirical findings, the model emphasizes the critical influence of spatial and physical studio configurations on students' cognitive, emotional, and behavioral responses. In particular, the study underscores the importance of aesthetic quality, ergonomic flexibility, technological integration, environmental comfort, and safety in shaping productive and supportive studio environments. It highlights spatial factors such as clear, open layouts; centralized or clustered configurations; adequate personal space aligned with anthropometric data; reconfigurable zones and movable furniture; wide, unobstructed circulation paths; and visual connectivity achieved through transparent materials and strategic spatial arrangement all of which contribute to enhanced user experience, collaboration, and academic engagement. Accordingly, this study offers a structured framework for studio planning and design, equipping educators, architects, and institutional policymakers with a blueprint to create inclusive, adaptive, and high-performing studio spaces that promote academic success, creativity, autonomy, and innovation in architectural education. Future research should evaluate students' perceptions and satisfaction with studio environments through a comprehensive assessment that includes all physical and spatial characteristics, test the proposed model in diverse contexts, and explore how emerging technologies and sustainable strategies can further enhance learning outcomes.

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Social housing dynamics: Adapting architectural design to evolving resident needs

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Abstract. Social housing is shaped by the changing needs and desires of its residents. This article examines the adaptability of social housing in response to changes initiated by residents and studies the Malagueira Neighborhood in Évora, Portugal, designed by Álvaro Siza, and Shushtar New Town in Iran, designed by Kameran Diba. Siza envisioned Malagueira as a flexible and evolving urban fabric, creating a structural yet open framework that allowed residents to personalize their spaces over time without compromising architectural coherence. Similarly, Diba's design for Shushtar New Town combined traditional Iranian urban patterns with modern housing needs, emphasizing a human-scaled environment that could adapt to residents' changing lifestyles. Based on documentary analysis, field observations, and academic sources, the study explores how residents interact with their environment and how it changes over time. The results show a complex relationship between the architect's initial intention and the changing needs of residents, reflecting broader social, economic, and cultural developments. Through a comparative analysis of the two case studies, the research identifies shared strategies and differences in how flexibility, resident participation, and architectural integrity are addressed. While both designs encouraged adaptation and sustained urban vitality, challenges such as infrastructure limitations, maintenance, and regulatory frameworks persist. Ultimately, this research contributes to discussions on sustainable and human-centered housing and provides insights into how flexibility can be integrated into future social housing developments without compromising architectural integrity.

Keywords: Social housing; Architectural flexibility; Resident transformations; Malaguera neighborhood; Shushtar New Town

1. Introduction

As urban populations grow and diversify, the challenge of designing housing that can meet the evolving needs of residents has become increasingly important. Flexibility and adaptability in architectural design are now recognized as critical strategies for fostering sustainable, human-centered communities. According to Davis (1995), "Social housing projects hold considerable historical and architectural significance within the realm of modern architecture. They arose in response to the urgent need for affordable and suitable housing". Social housing is not simply shelter or protection from the outside environment. Rather, it should deliver a sense of dignity and pride to its inhabitants through its architectural style, materials, and design (Amirjani, 2020). The term itself implies that a responsible and humane society has an obligation to assist those who cannot afford the free market price of housing (Davis, 1995).

As many studies have indicated, affordable housing and decent housing is a primary need, and also a human right, which has an effect on the education, health and employment productivity of the inhabitants, as well as on the general well-being of the society. Among the notable examples of such adaptable social housing are the Malagueira Neighborhood in Évora, Portugal, designed by Álvaro Siza, and the Shushtar New Town in Iran, designed by Kamran Diba.. Both projects, although rooted in different cultural and historical contexts, share a common commitment to creating living environments that respect traditional patterns while allowing for future growth and personalization.In general ‹Siza and Diba executed their housing projects during a specific historical period (1977), employing similar strategies, ideas, and design concepts (Amirjani, 2017).

The two aforementioned projects were destined to be unique 20th-century designs due to the architects' intense focus on their traditional, cultural, social, and historical elements. In Malaguera, Siza's strategy placed a strong emphasis on structural openness, which promoted residents' gradual modifications and preserved the

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neighborhood's architectural coherence. In parallel, the new city of Shushtar Diba reinterpreted vernacular Iranian urbanism to create an environment that was human-scale and responsive to the daily lives of its residents.

The purpose of this study is to find out how social housing can adapt to residents' evolving needs over time without compromising social cohesiveness or architectural integrity.

By conducting a comparative analysis of Malaguera and the new city of Shushtar, this study seeks to identify key strategies and challenges related to resilience, resident participation, and sustainability. Ultimately, the findings contribute to broader discussions on the design of resilient and adaptive urban environments appropriate to contemporary and future social developments.

2. The emergence of the Malagueira Neighborhood and Shushtar New Town

Following the so-called "White Revolution" in Portugal in April 1974, which marked the end of 48 years of dictatorship, the newly appointed Minister of Housing and Urban Development set out to address the country's housing shortage. The Malagueira Housing Project was a component of Évora's broader social housing program. While building 1,200 affordable housing units suitable for middle-class and lower-class populations on a 27-hectare plot of land, the goal was to preserve Évora's cultural features. Within four months, Siza developed the initial strategic design, and the project board approved the final architectural plans in November 1977. Out of the 1,200 planned residential units, 1,100 had been built by July 1997, with the entire project completed by 1998 (Zapatel, 2001).

In a different geographical context, far from the West, where modernization started, Iran saw the rise of social housing and corporate towns as a direct result of rural-urban migration to industrial areas and larger urban centers.

This population shift was predominantly driven by the White Revolution, a modernization program executed in Iran between 1963 and 1979 (Mohammadpanah, 2022).

Shushtar New Town is located near the historic city of Shushtar in Khuzestan Province , southwestern Iran. The project was designed to house the workers of the Karun Agro-Industry Company, one of the largest sugarcane production industries in the region(Shirazi, 2016). The town wanted to support the growth of the local sugarcane industry by giving its workers access to modern living facilities.

The project was to be completed in five phases by 1985. Construction of the first phase, which was intended to house 4200 residents, started in 1976 and was almost completed, with 600 units built, between 1977 and 1980 (Sedighi, 2016).

In fact, both projects are clustered low-rise carpet housing with Medium-Density settlements(Amirjani, 2020). The Shushtar New Town project is situated on a gently undulating site near Shushtar, offering river views (Diba, 1981). In contrast, Malagueira is located in Évora, a historic city in Portugal that is characterized by its gentle slopes and rich Roman heritage. Both locations experience extremely hot summers and mildly dry winters(Amirjani, 2017) (Fig. 1 and Fig. 2).

Fig. 1. Bairro da Malagueira, Évora, Portugal, 1987

Fig. 2. Shushtar New Town, Shushtar, Iran, 1976

3. Flexibility in architecture

Any space system with the ability to change internally can respond to a greater number of needs of its users at different times and thus have a more desirable function than single-function space systems. A subfield of the field of space flexibility is the achievement of changeability in space systems. In recent years, a number of researchers have examined the problem of flexibility in architectural spaces, which has drawn increasing attention from the architectural community. One key reason for this attention is the need to accommodate and ensure the fulfillment of various user needs at different times. It is anticipated that this feature can be used for a variety of purposes due to the effectiveness of flexible design. Since the home is where people spend the most time out of all the different uses, it is crucial that it be able to accommodate the various (and occasionally conflicting) needs of its occupants (Wielland & Wallburg, 2012: 890).

In addition, the way residents use their homes tends to change more rapidly than in other building types, which requires the living space to adapt to a diversity of activities. Based on this perspective, flexibility in housing emerges as one of the key concepts in this field. By comparing different residential models, it is possible to analyze how this concept has evolved over different periods in the development of Iranian domestic architecture. ibid

In fact, flexibility in the early stages of design refers to the initial thinking in the design process and how to arrange the space in a way that can accept changes. It includes a chain of physical changes that provide the building with the ability to adapt to changing conditions (Habraken, 2008: 291).

Meanwhile, Gruter believes that complete flexibility is not possible and that there are limits to this, because the entire system and its original structure must be preserved(Grutter, 1987). According to the above definitions, flexibility can be understood as the ability to make changes that involve both the field of activity and the architectural form, in order to meet user needs. In other words, whenever user needs arise regardless of time or place flexibility enables the spatial and activity systems to adapt accordingly. Moreover, a change in the activity system may require the user to modify a specific architectural element in a specific location to better accommodate those needs.

This concept of flexibility is clearly evident in notable residential projects such as Malaguera by Álvaro Siza and Shushtar New town by Kamran Diba, each of which demonstrates a distinct but contextually rooted approach to adaptive residential design. Both architects incorporated the flexibility of unit extension into their design approach, allowing for future expansions of the dwellings. In Malagueira, Siza implemented building regulations that allowed for the evolution of unit plans and the merging of adjacent houses. Similarly, Diba incorporated a design concept in Shushtar New Town that facilitated the growth and extension of houses through simple modifications to the walls between units(Rodrigues, 2015).

According to Diba, this design approach prevents stagnation in the urban fabric while enhancing the eco-dynamic, social sustainability, and diversity of families residing in the area(Eloy, 2018).

In Malaguera, Siza uses a modular and expandable system in which residential units are built according to simple, repeatable typologies. This allows residents to modify or expand their living spaces over time according to changing needs. The uniformity of the infrastructure – particularly the system of elevated concrete channels used for utilities – ensures that the houses can evolve without disrupting the overall urban plan. The architectural form, while visually coherent, is intentionally open to user-driven change and embraces the core principles of flexibility(mota, 2014). Conversely, Shushtar New Town, on the other hand, represents an indigenous and culturally sensitive interpretation of flexibility. Diba encourages a variety of social and practical uses by incorporating traditional Iranian architectural features like courtyards, winding passageways, and flexible semi-public areas. There is flexibility in the residential designs. They adapt to changes in lifestyle, family structure, and even small-scale commercial use in the future. The project's spatial arrangement encourages social interaction while letting each unit change to reflect the needs of its occupants(Amirjani, 2020) (Fig 3 and Fig 4).

Fig. 3. Aerial view, currunt situation, Bairro da Malagueira, Évora, Portugal,1987

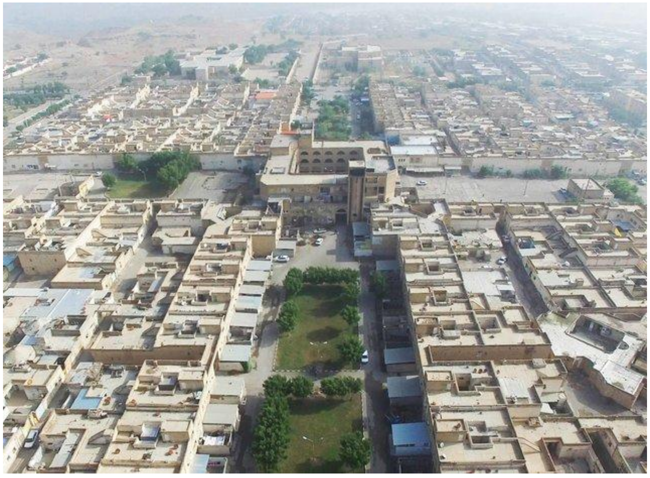

Fig. 4. Aerial view, current situation, Shushtar New Town, Shushtar, Iran, 1976 (Amirjani, 2017)

4. Architecture with the people, by the people, for the people Malagueira designed by Alvaro Siza

In fact, the conflict between ownership and the right of residents to personalise the design has been another universal challenge in creating sustainable social housing. However, some architects and government agencies have come up with innovative solutions for responding to this conflict. Alvaro Siza uses a unique approach to design in which users actively participate in the shaping of designs and ideas. This practice, called participatory methodology, is seen throughout Siza's housing design and aims to reflect the wishes of the people and to revive the relationship between the designer and the users. In the Malaguera project, Siza began his work with conversations with future users, authorities, and representatives of the local housing cooperative, and from these conversations, concepts and initial designs were formed (Mota, 2011).

After completing the designs, Siza proceeded to build several full-scale models of spaces such as the rooms, kitchens, and living rooms using lightweight blocks to explore client feedback on their ideas and spatial experience. Siza frequently highlights the value of user interaction, viewing it as one of the key tenets that ought to be given top priority throughout the entire design process. However, expressing all the requirements and demands could be frustrating and time-consuming for a designer. According to Siza, responses from authorities and users can sometimes be tyrannical and authoritarian; they try to impose their point of view while rejecting all architectural complexity. According to Siza, a designer could just accept this drawn-out process in order to avoid conversations, but a genuine engagement process requires that one accept tensions because the outcomes of these interactions are crucial (Zapatel, 2001).

It can be argued that these direct interviews not only improve the dialogue between "object" and "subject" by reflecting the demands of users, but they also help architects become more aware of how well their design concepts and ideas are received by the residents. Álvaro Siza originally planned a 3.5-meter wall separating public and private areas in the Malagueira housing project (Siza, 1979), However, he added a window facing the street and lowered the wall after residents complained that the house was too obstructed, striking a balance between social interaction and privacy (Leger, 2004). These changes helped to reflect the cultural and social preferences of the early residents and the contrast between closed and open design. Early occupants designed more varied and intimate areas with shorter walls, whereas government-built units with taller, more homogeneous walls showed less evidence of personal identity. (Sennett, 2018).

Table 1. Resident-led spatial transformation, Malagueira, Portugal

Reasons	Spatial Transformation	Visual Documents
Modification of boundary walls Mean	Originally designed with 3.5-meter-high walls between public and private spaces, the wall height was later reduced and a window was added facing the street in response to resident complaints about excessive enclosure	 
Contrast in wall heights between unit types	Early resident-built units featured shorter. more personalized walls, while government-constructed units retained taller, uniform walls, resulting in less expression of individual identity	 
Informal conversion of streets into parking	Streets were intentionally designed without sidewalks or parking to promote social interaction, inspired by traditional Alentejo villages. However, residents' refusal to purchase garages led to the use of these spaces as informal parking, undermining the project's original communal Vision	 

Due to residents' reluctance to buy garages, the Malagueira neighborhood's winding streets, which were intended to promote social interaction by avoiding sidewalks and parking spaces and drawing inspiration from Alentejo village life, gradually became unofficial parking areas (Gomes, 2016). Siza's idea of a vibrant, social street life was weakened by this change. High walls stayed the same in the areas created by the government organization FFH, creating a more constrained and closed streetscape. Public opinion was sharply divided after the first units were built in Malagueira; some locals referred to it as “the Arab neighborhood,” criticizing the monotony and comparing the houses to animal pens (Robalo, 1983). Siza accepted the critique and underlined that using aesthetics alone to combat monotony would lead to artificiality (Siza, 2009). Although there was disagreement over the exterior homogeneity, subsequent reports commended the homes' interior comfort and quality (Rocha, 1985).

In actuality, the Malagueira Neighborhood project evolved into a platform for political conflict that transcended its unique advantages and disadvantages. The Malagueira plan was perhaps the most significant example of a participatory design decision-making process created in Portugal following the post-revolutionary experience with citizens' participation during the SAAL process, despite the challenging circumstances in which the project's development was managed. However, Siza believes that involvement involves more than just a conciliatory strategy. It’s also about exploring the creative potential of conflicts. Architectural historian Kenneth Frampton made the following argument in reference to Siza's experience with citizen participation in the design process: "In hindsight, this intense and challenging experience has led him to caution against the simplistic populism of 'giving the people what they want.'" (Frampton, 1986).

Definitely, the conflicts between the architect and the other stakeholders in the process became part and parcel of the design process and played an important role in the processes of subjectivation. Siza claimed, “Participation procedures are above all critical processes for the transformation of thought, not only of the inhabitants’ idea of themselves but also of the concepts of the architect” (Siza and Vanlaethem, 1983).

In many cases, the residents changed the circulation structure of the house and connected the patio directly to the roof terrace on the first floor, a possibility that Siza had not considered in the initial versions of the project. By doing so, the residents enlarged their sky-facing spaces and also expanded the functional possibilities of the house. Now, the roof terraces could be used for drying clothes or just to give first-floor bedrooms direct access from the patio. The patio became a privileged territory for the production of subjectivity (Gomes, 2016).

5. Shushtar New Town Kamran Diba

The Design Method of Kamran Diba in Shushtar New Town It is possible to conclude from examining Kamran Diba's architectural sketches and interviews about Shushtar New Town that the architect used what can be referred to as a "sentimental approach" when designing the project. This approach was based on feelings, memories, tenderness, and utopian nostalgia for a vanished past and a world that is disappearing.

This, along with Diba's intentions of "reviving the traditions" and "resisting the universal mass production culture," played a key role in the creation of the Shushtar New Town project.

As Diba has stated time and time again, "When designing social housing in any culture, users have a particular lifestyle with certain needs," and the architect's primary duty is to address these common needs while having a thorough awareness of people's lives (Khanizad, 2014). Diba's understanding of the distinctive way of life of the locals was evident in his early plans for the Shushtar New Town. Diba's own sentiments and emotions are also conveyed, along with his longing to bring back his adolescent and childhood memories of living in the contemporary uptown Tehran neighborhoods and his longing for the dwindling traditional Iranian way of life (Daneshvar, 2016).

Shushtar New Town is a creative recreation of the traditional housing pattern that simultaneously meets the needs of contemporary life. This complex's design incorporates innovative elements of traditional urban planning and lifestyle, such as a compact texture, rooftops that can be used for nighttime sleeping, thick walls, dead-end alleys, narrow streets, and small windows that create a cozy and comfortable atmosphere (Diba 1980). "We planned two- and three-room housing units that could become four-, five-, or six-room houses as the family's standard of living improved." (Diba 1980). This flexible configuration, what Diba calls "soft furniture" (Javaherian and Diba, 2005), enables residents to move between different spaces to avoid the sun or to enjoy it in different seasons. The rooms measure 5×5 m, 4×4 m, and 3×4 m, with the smallest being the smallest. On this flexibility, Diba writes: "Our goal was akin to writing a script for human interaction, anticipating all possible action and yet leaving room for spontaneous improvisation within the given architectural spaces." (Diba 1980). A distinctive feature of Diba's reinterpretation and unique approach to new creation is the way he subtly deconstructs and reframes traditional architectural and urban principles to achieve new designs and configurations. This process of de-familiarization creates a context of tension in which the familiar and the unfamiliar are brought together in a dialectical interaction(Amirjani, 2017).

5.1. Spatial transformations and structural damages caused by resident-led ınterventions in Shushtar New Town

Shushtar New Town's design and construction started in 1974. Due to Diba's departure from Iran and the changes brought about by the revolution, the complex's construction was initially sluggish and eventually came to a complete halt in 1979. Following the start of the Iran-Iraq War, most of the original residents left the buildings, and war victims along with immigrants from various cities, villages, and surrounding areas moved into this town and settled there. The arrival of war refugees to the unfinished New Shushtar; the social structure of the city could not be well organized and could not be a good host for its residents along with its physical structure As a result, the town reached the stage of occupancy before it was truly ready and under unauthorized conditions. The town's inhabitants, each contributing their own customs and cultures, stayed for eight years, allowing for the project to undergo changes. This was because everyone brought the culture and customs of their respective cities to the complex. However, their overcrowding caused the complex to sustain additional damage (Amirjani, 2017).

From the start, Shushtar New Town's design demonstrated a tension between users' real lifestyles and Diba's perception. Shortly after occupancy in 1979, two major privacy-driven transformations occurred: windcatcher holes were filled, and openings facing pedestrian walkways were blocked. In courtyard and apartment typologies, ground-level windows compromised privacy, leading residents to wall them off. During the Iran-Iraq war, overpopulation caused shared use of units and extensive interior modifications, such as building new walls, transforming balconies, and altering entrances (Bakhtiari & Mosavi, 2017). Diba's design excluded cars from narrow alleys to enhance comfort, safety, and environmental quality, with parking placed at the street ends (Diba, 1980). However, insecurity and vehicle theft led residents to modify homes to accommodate cars, often demolishing courtyard walls. These changes, including roofing courtyards and blocking windows, disrupted the original spatial logic and image of the town (Daneshvar, 2005).

5.2. Physical pathography

Physical injuries in the complex include:

- Humidity
- Flowing sewage in the area
- Accumulation of loose waste in the complex
- Inappropriate additions
- Deterioration of some walls and flooring in the passageways over time
- Failure to repair and address existing damage
- Lack of plumbing (gas, water, electricity, and sewage) in some parts of the complex

- Closure of air vents and alteration of the balcony parapet height

Table 2. Resident-led spatial transformation, Shushtar New Town, Iran

Reasons	Spatial Transformation	Visual Documents
Privacy	• Filling the windcatcher holes located in the walls of the courtyard • Blocking openings facing pedestrian crossings • Creating a roof for the courtyard and blocking the windows to prevent visual access of other units	 
Security	• Converting a private yard into a parking lot • Replacing the entry doors with gate-like doors for cars • Extending the wall up to the second floor and roofing the void from the to • Transforming the rooms according to their own condition and needs	 
War	• Builting walls inside the rooms, creating new spaces for sleeping, or as kitchens • Converting a large number of balconies into small rooms	

5.2.1. Windows

The following are the reasons why residents have altered their windows:

The primary rationale behind window modifications is the necessity to create more space. In other words, many changes in window openings have resulted from residents' interior home modifications made to accommodate spatial needs.

- Unsuitability of the window for its intended use: This is a reference to the prevalent use of air conditioners and other cooling devices in this region. The window openings' dimensions, shapes, and proportions do not satisfy the users' needs for comfortable living spaces.
- Creating privacy: A few residents have expressed dissatisfaction over being able to see inside their homes. To address this, they have altered the windows to enhance and ensure their privacy.
- Enhancing the sense of security (security against theft).
- Increasing the Feeling of Protection (protection of people and objects from falling).
- Amount of Natural Light: Customers have complained that the units do not get enough natural light. However, this factor has been the least important reason for users to make changes to the windows. Among the reasons for this are the heat and climatic conditions.

Additionally, the most important methods of making changes, in order of priority, include changing the use of the space behind the window, altering the location of the opening, changing the size of the opening, and modifying the shape of the opening.

6. Conclusion

This study highlights the subtle yet important conflict between the original architectural vision and the realities of daily life as shaped by the locals in the Malagueira Neighborhood and Shushtar New Town. In both situations, people's gradual adaptation of their living spaces was greatly influenced by the lack of a clear post-occupancy management plan and continuous supervision. The majority of people in Shushtar New Town made modifications mainly to accommodate their basic needs, which included wanting more privacy and space. However, cultural context was not given much thought when many of these changes occurred. Research has indicated that the initial spatial arrangement did not offer sufficient comfort or a feeling of safety, resulting in discontent, particularly with regard to privacy. The fact that the project ultimately housed a population that was primarily made up of immigrants, which was not foreseen in the early planning stages, further complicates matters. Events like the Iran-Iraq War, alongside administrative mismanagement, only deepened the challenges. Because designers and potential residents did not communicate well, the architecture frequently did not represent the daily lives of the occupants. These findings imply that more successful outcomes might have been achieved by incorporating users earlier in the process and raising awareness of their social and cultural customs.

By contrast, Malagueira presents a more optimistic picture. Álvaro Siza's approach provided a flexible but coherent urban system where people could gradually personalize their houses. This flexibility helped maintain architectural unity while making space for individual needs to emerge. Residents felt more in control of their surroundings and had more agency because of the design process's participatory nature, even though the neighborhood also had problems, such as shared streets being turned into unofficial parking lots.

These two instances unequivocally demonstrate that social housing is a story that continues after construction is completed. When people are left to adapt mass-produced housing on their own without supervision, the lack of planning or regulations frequently results in chaos and a decline in the quality of the design. Sustainable housing demands more than just good design, particularly when it comes to large-scale projects. It requires careful maintenance that lasts long after residents move in. Ultimately, designing housing that not only lasts but also changes gracefully with its occupants requires a deeper understanding of culture, early user involvement, and an architecture that permits change.

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Enhancing visitor experiences in cultural heritage sites through AI-Driven smart system

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Abstract. As cultural heritage sites globally face challenges in preservation and visitor engagement, this research explores the integration of AI-driven smart systems to enrich the visitor experience, with a focus on the ancient cities of the Troas region. The study addresses the challenges of preserving and presenting complex historical narratives, particularly in archaeological sites where traditional static informational tools (e.g., brochures, display boards) often fail to provide meaningful and interactive experiences.The proposed solution combines deep learning (DL) and augmented reality (AR) technologies to develop an intelligent information system that enriches the visitor experience while promoting the sustainability of cultural heritage. The system integrates two key AI fields: computer vision (CV) for object detection (OD) and natural language processing (NLP) for personalized content delivery. By identifying key architectural elements and artifacts on-site, the system provides context-aware, interactive narratives tailored to each visitor's interests and knowledge level. This dual-modality approach enhances both intellectual and sensory accessibility, fostering deeper engagement through multi-sensory storytelling and dynamic interaction. Conceptually, the study is grounded in John Dewey's theory of experience, which emphasizes the active and continuous interaction between individuals and their environment. The system aims to transform passive observation into active participation by stimulating curiosity and enabling personalized exploration. This approach not only increases cultural awareness but also improves knowledge retention, making the experience more meaningful for visitors. Preliminary results from fieldwork in the Troas region, including Alexandria Troas, Apollon Smintheion, Assos, and Parion, indicate that interactive, AI-powered environments hold significant potential for creating immersive and contextually enriched heritage experiences. The findings are expected to contribute to both architectural and technological fields, offering a scalable model for similar cultural heritage preservation efforts globally. By aligning digital innovation with the ethical imperatives of heritage conservation, this study highlights how advanced technologies can foster new opportunities for sustainable and meaningful visitor engagement across cultural heritage sites globally.

Keywords: Artificial Intelligence; Cultural Heritage Sites; Visitor Experience; Deep Learning.

1. Introduction

The preservation and presentation of cultural heritage sites, which contain valuable information such as daily life, economic situation and aesthetic perception, presents a context that needs to be addressed in a special way. In particular, archaeological sites, whose different historical layers have disappeared or have been articulated during the historical process, have difficulty in interacting with visitors. Although additional resources such as information boards and brochures are used to increase the quality of the experience, they are not sufficient to convey the historical and cultural value of the cultural asset (Anay et al., 2022). These structures and artifacts, which were built at a time in history, are open to connecting with people as soon as they are uncovered. On the other hand, for the visitor who does not have expert knowledge, the main problem is to understand and interpret the multi-layered and at the same time incomplete data presented by the site. Therefore, improving the visitor experience in these areas is of great importance in creating cultural heritage awareness and ensuring its sustainability and transferring it to future generations.

With the aforementioned problem framework, the study proposes a proof-of-concept model for an AI-driven intelligent information system for enhancing visitor experience in cultural heritage sites. It aims to develop a system that aims to provide an intelligent and interactive information system and an "augmented" environment

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fed by this system by combining the potentials of Large Language Model (LLM) under Natural Language Processing (NLP) and Object Detection (OD) under Computer Vision (CV). With this intelligent information system, it aims to enrich the cultural heritage site experience and make it meaningful. In this context, the Ancient Troas region is considered for the proposed intelligent information system, and the ancient cities of Alexandria Troas, Apollon Smintheion, Assos and Parion in the region and the Classical Architecture assets they contain constitute the application framework of the study.

The “experience” mentioned here is a term that has the ability to create a common synthesis by bringing together many concepts and meanings. At this point, theoretically, the study is based on John Dewey's theory of experience. John Dewey(1986) defines experience as a relationship between nature and organism. This relationship is an interactive communication process between the object and the subject (human). Both sides form a whole with their own unique qualities as known or knower according to each other. This interaction between the organism and nature occurs at every moment of life, so experience is continuous and means “experienced situations/things”. The individual is not only a passive observer in this interaction, but also an actor who is affected by his/her environment, reacts to it, makes sense of the elements of experience with his/her senses and mind, and is transformed in this process. The individual who can develop himself/herself by extracting information and meaning from some external inputs sometimes gains habits. Dewey defines this process as experience (Dewey, 2008). Dewey's definition provides an important framework for examining the problems encountered in the presentation of archaeological sites to visitors and visitor expectations. With a Dewey’s perspective, the presentation of archaeological sites can gain meaning through a much more interactive and richer approach that integrates with the visitor and encourages them to explore its different layers. On the basis of this approach, the study reconstructs the visitor experience as an interactive, contextualized and layered experience of place and story, rather than a mere transmission of information.

2. Methodology

The study proposes a proof-of-concept model for an AI-driven intelligent information system for enhancing visitor experience in cultural heritage sites and adopts a two-stage research design. In the first stage, a literature review was conducted to establish the theoretical and conceptual foundation of the model. As such, the theoretical background of the study is examined under three main headings: Dewey's theory of experience, experience in archaeological sites, which are important cultural heritage sites, and AI applications in cultural heritage sites. The theoretical background of the study was created by reviewing articles, conference proceedings and books on these topics.

In the second phase, an intelligent, interactive and context-aware information system model built on this foundation is presented. This system aims to identify architectural elements through OD, which is one of the fields of AI, to provide personalized content tailored to the visitor's own interests through NLP, and to make these processes possible in a multi-sensory experience environment through AR.

For the data set of the study, data collection was carried out in an unstudied area (Ancient Cities of Troas Region, Classical Architecture) with on-site video shootings, and a unique data set that did not exist before is being created.

2.1. System Design

The system design of the proposed intelligent information system is given in the Fig. 1. At this stage, after the integration of OD module and NLP, it is aimed to transform the system into a holistic structure by developing the information database with interface design and integrating this database through the Information Retrieval System to be designed.

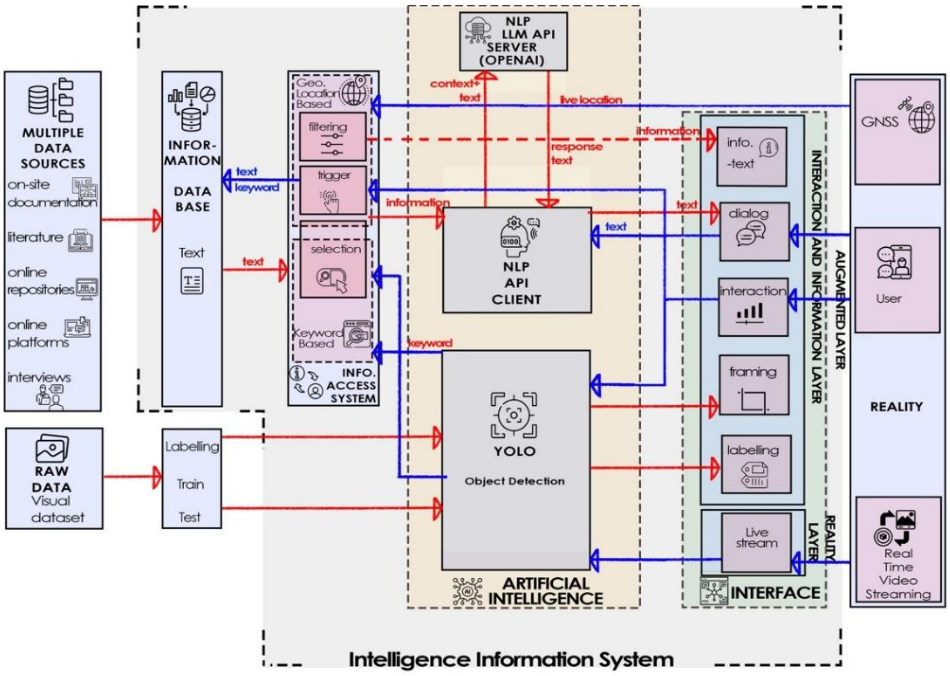

Fig. 1. System Design.

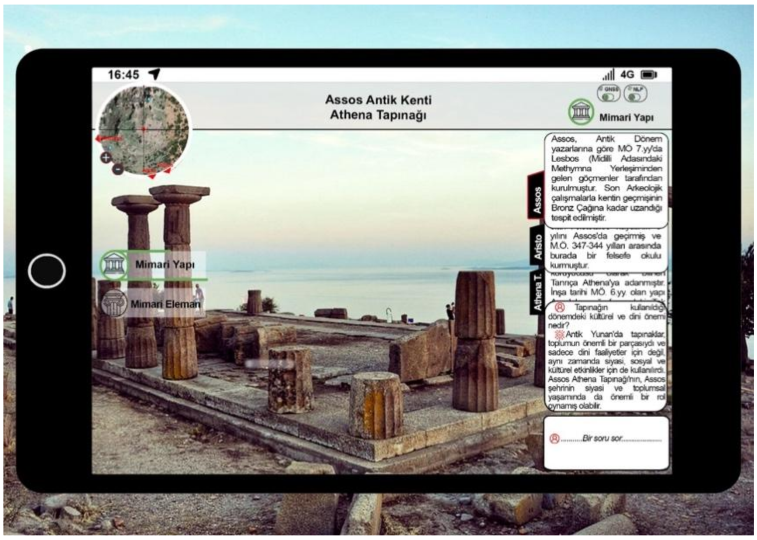

Fig. 2. Concept/Scenario 1 (Architecture).

The system receives the current position from the GNSS. Accesses the Geolocation based triggering module in the Information Access System. If the location is within an area in the database, it filters the relevant database and highlights it. Basic information about the area fills the first information tab. An aerial photo of the area is placed on the mini-map. A location-based search/selection is performed in the selected database. Important points (architectural elements, stories, events, people, etc.) around the location are identified. Distant elements in the immediate vicinity of the location (but not in its sphere of influence) are marked on the mini-map with direction markers. For example, Theater, Agora and Necropolis are marked on the map. Information about the elements within the sphere of influence is retrieved from the database and fills the other tabs. For example, in the image, the ancient city of Assos, Aristotle, who is known to have spent 3 years here and laid the foundations of western philosophy at that time, and the Temple of Athena, which the user was standing in front of at that time, are the items that fill the tabs. The user can get basic information by selecting the tab of their choice. This information also feeds the NLP module. The system first transmits the data obtained in the process outlined above through the client to the NLP server as the "context" of the dialog (contextual preprocessing). If the user enters a dialog, a dialog evolves based on the currently selected tab. The dialog is contextual, but open-ended.

Fig. 3.Concept/Scenario 2 (Architectural Element).

The system receives the current position from the GNSS. It accesses the Geolocation based search module in the Information Retrieval System. If the location is within an area in the database or in the domain of an important structure, this information is processed in the title and mini-map. For example, in the image, the information about the Sanctuary of Apollo Smintheus (area) and Sminthéion (architectural element) is entered in the title, while the mini-map contains information about the bathhouse, street and water tank. When the system is operated at the architectural element scale, no filtering and triggering is done for elements related to the area, architecture, story, event, etc. from the database. The Architectural Element module is location independent, universal, and works in areas that are not in the database.

OD module is active. The system examines the streaming image and performs classification and labeling. The labels are not completely processed into the image, but the labels are transmitted to the keyword-based search module of the Information Retrieval system and the tabs are filled with the returned information. In the example image, 5 elements are identified as Frieze, Architrave, Ionic Cap, Fluted Column Body and Pedestal. Since the user clicks on the Frieze tab, the Frieze element in the image is labeled and the relevant information tab is active. This information also feeds the NLP module. The system first transmits the data obtained in the process outlined above through the client to the NLP server as the "context" of the dialog (contextual preprocessing). If the user enters a dialog, a dialog evolves based on the currently selected tab. The dialog is contextual, but open-ended.

3. Theoretical Framework

The study addresses the issue of "historical (architectural) conservation and the experientialization and sustainability of cultural heritage", which is a specific problem situation in the field of architecture, through John Dewey's theory of experience, and aims to investigate the potential of DL research under AI towards this issue. As such, the theoretical background of the study is examined under three main headings: Dewey's theory of experience, experience in archaeological sites, and AI applications in cultural heritage sites. An important group of references in connection with the focus of the research are the motivations for the use of DL applications in the intersection of architecture and cultural heritage and the studies that include different examples in these fields.

3.1. Visitor Experience in Archaeological Sites

Archaeological sites are underground, aboveground and underwater areas that contain social, cultural and economic traces that have reached the present day since the existence of humanity. These sites have the quality of historical documents where clues about the life of the societies living in the past can be traced (ICOMOS, 1990). This definition makes archaeological sites more than just being environments that contain "things" from the past; they are also important in making sense of the past, enriching social identities and transferring the accumulation of knowledge that has continued in the historical process to future generations (Özdoğan, 2008). However, from the time they were built to the present day, these spaces are difficult to read and require expertise due to the historical layers they have lost or added (Anay et al., 2023). Hall and McArthur (1996) emphasized that visitor experience is a priority for cultural heritage sites and their management, and stated that visitors should be given enough importance for effective cultural heritage management. In order to achieve this, they argued that the visitor experience should be improved and thus visitors should be encouraged to behave more responsibly towards these sites.

Briefly defined, visitor experience is defined as a subjective or personal reaction to activities, environments or situations outside of one's usual environment (Packer & Ballantyne, 2002). Here, the experience starts with the individual's motivation to visit the site and ends with the benefits gained during and after the visit (Tezgel & Akova, 2017). The visitor experience in cultural heritage sites such as museums and archaeological sites can be defined as a kind of "dialogue" between the site and the individual (McCarthy & Ciolfi, 2008). Visitors' experiences in cultural heritage sites are related to complex factors such as individual characteristics, interests and physical conditions of the site (Falk & Dierking, 1992). In addition, individuals' reasons for visiting such sites may be based on a conscious choice or by chance. This creates diversity in the motivations and expectations of visitors (Kempiak, Hollywood, Bolan, & McMahon, 2017). For a consciously planned visitor, the primary purpose may be to gain information, whereas for an accidental visitor, factors such as the desire to discover new places, having fun and having a pleasant time may be at the forefront. Masberg and Silverman (1996) and Packer and Ballantyne (2002) state that the main motivation for visitors to experience cultural heritage sites is to gain information. While Moscardo (1996) evaluated the reasons why visitors come to these sites under three main headings: entertainment, information and social interaction; Poria et al. (2004) based the experience of cultural heritage sites on five main reasons: information, creating cultural heritage awareness and the desire to pass it on to future generations, connecting with cultural heritage and having fun.

When cultural heritage sites are considered on the basis of visitors with quite different motivations and expectations from each other, the first step can be seen as the identification of themes that can attract attention in order to meet these expectations and ensure cultural heritage transmission. For example, narratives about a past event, story, a person's life, beliefs, aspirations, longings and fears are such interesting for visitors. The sense of curiosity about past life/human experiences is an interesting subject for today's people. Therefore, themes that can arouse curiosity in visitors and enable them to make past-present comparisons provide an opportunity to present archaeological sites in a memorable and interesting way (Moshenska, 2017). In addition to the content of the experience that will arouse curiosity, the senses of the visitor also play an important role. Visual, auditory and sometimes even olfactory senses become important for the visitor who experiences an archaeological site to make sense of the structure and its function. In fact, the narratives and sounds experienced regarding the usage scenario of the building/building remains are powerful sources of teaching and reminding. In this way, the visitor has the opportunity to interact with the building and its surroundings, and tries to listen and feel the space (Silberman, 2015). At this point, applications that visitors can use with their mobile devices provide advantages in the presentation of archaeological sites. In particular, applications that can be personalized and where the visitor can obtain information in line with their curiosity and interest stand out. This kind of presentation method can be incorporated into the experience without the hassle and complexity of learning how to use the device. In addition, the ability of the visitor to choose their own stopping and waiting points has a positive effect on the sustainability of the experience (Grima, 2017). It is thought that the way of inviting individuals to be present and connect with the site, which Li and Jia (2010) mentioned as one of the main objectives of cultural heritage sites, can be achieved by using digital tools effectively and creatively to make sense of the historical environment.

3.2. John Dewey's Theory of "Experience"

John Dewey (1986) defines experience as a relationship between nature and organism. This relationship is an interactive communication process between the object and the subject (human/knowing). Both sides form a whole with their own unique qualities as known or knower according to each other. This interaction between organism and nature occurs at every moment of life, so experience is continuous and refers to "experienced situations/things". But often experience is ambiguous. Events happen in the course of everyday life but may not become experience. There is a distraction when our observations, thoughts and feelings conflict with each other. We start something but sometimes stop before completing it. On the contrary, when the experienced situation continues in its normal course and is completed, it becomes an experience. When a problem is solved, a game is played, or whatever the experienced situation is, an action is complete when it ends satisfactorily. This doesn't have to be an ending; what the experience needs is completion. Such a situation is complete in itself and fulfills the necessary qualifications (Dewey, 1986). Dewey states that such a situation can be defined as experience.

We can have many experiences in our daily lives that have different levels of significance. All of these experiences have their own beginning and end, their own internal characteristics and dynamics. A meal eaten in a nice restaurant that is etched in our memory and a catastrophe experienced can also be described as experiences. In such experiences, from the beginning to the end, the parts have a flow within themselves. Each part leads to the next and this continuity causes the parts to become clearer. Thus, all these successive parts form a permanent whole of experience. Within this whole, there are sometimes some pauses. However, these prevent the continuous acceleration of the parts, summarize and define the events experienced. Just as in a conversation, speakers use variable emotions and expressions according to the flow of the conversation in their own unique characters (Dewey, 1986). According to Dewey, experience, which is such a continuous and dynamic process, is fed by the interaction between the individual's inner world and inputs from the external environment. This continuity of experience contributes to the emergence of certain habits in the individual, helps him/her to improve himself/herself in relation to the subject experienced, and to develop his/her creative thinking ability. However, if an experience arouses curiosity in the individual or increases the desire to take action, it can offer new goals to the individual. So every experience is also a source of motivation. The habit development feature of experience also shows that it is an educational process. Dewey says that the continuity of experience should be considered together with interaction. As long as the individual continues his/her life and learns, the process of experience continues. If this relationship is broken, the ability of experiences to qualify and develop each other is disrupted (Dewey, 2008). For Dewey, it is sensations that enable perception of environmental conditions and concretization of experience. A guitarist can improve himself by experiencing sensations over and over again, or a tailor can become a master through the repetition of sensations. As in these examples, the comprehension of the principles that enable one to master a subject is through the reference provided by sensations. Through these sensations, humans strengthen their interaction with the object (Dewey, 2008). For this reason, Dewey defined sensations as one of the integral elements of experience.

When considered within the framework of Dewey's definition of experience, the presentation of archaeological sites will gain meaning with an approach that is much more interactive, rich, integrating with the visitor and encouraging them to discover layers of meaning. In order to make sense of the multi-layered but incomplete and ambiguous data-presenting structure of archaeological sites, it points to the existence of a multi-sensory, interactive tool that will awaken the consciousness of the visitor and push them to feel the site. However, it is understood that visitors experience cultural heritage sites with different motivations and therefore their expectations vary. However, no matter how diverse the visitor profile of these sites, the basic expectations of acquiring information, having fun and connecting with the site stand out. For visitors who actively participate in the experience while gaining information, the experience of the place becomes more meaningful and the knowledge gained becomes permanent. In this way, visitors can not only observe the area but also establish a connection with the architectural structures and elements. Visitors who participate in the experience and feel that they are a part of the area by controlling it can gain cultural heritage awareness. All these elements increase the general satisfaction level of visitors and create a sense of curiosity towards cultural heritage, history and culture. Each visit is decisive for the next heritage site experience and is an encouraging experience for the visitor who meets their expectations. This plays a vital role in preserving cultural heritage and ensuring its transmission to future generations.

3.3. AI in Cultural Heritage Areas

One of the AI-driven studies carried out in cultural heritage sites is the architectural style identification and classification study carried out by Shalunts et al. (2011). The researchers carry out building style classification using DL over the window element with the idea that the architectural styles discussed in the study (Romanesque-Gothic-Baroque) have a typical window style. Accordingly, in the study, DL was able to categorize the structures as Romanesque, Gothic or Baroque using visual data. The researchers reveal that a database categorized based on architectural style in this way will produce effective and fast results in studies such as 3D reconstruction, urban modeling, virtual tourism and cultural heritage protection. Again, Shalunts et al. (2015) conducted a study for the identification of the tower structural element and the classification of the buildings. The results reveal that with high verification rates, architectural styles can be distinguished from the distinctive features of the structures.

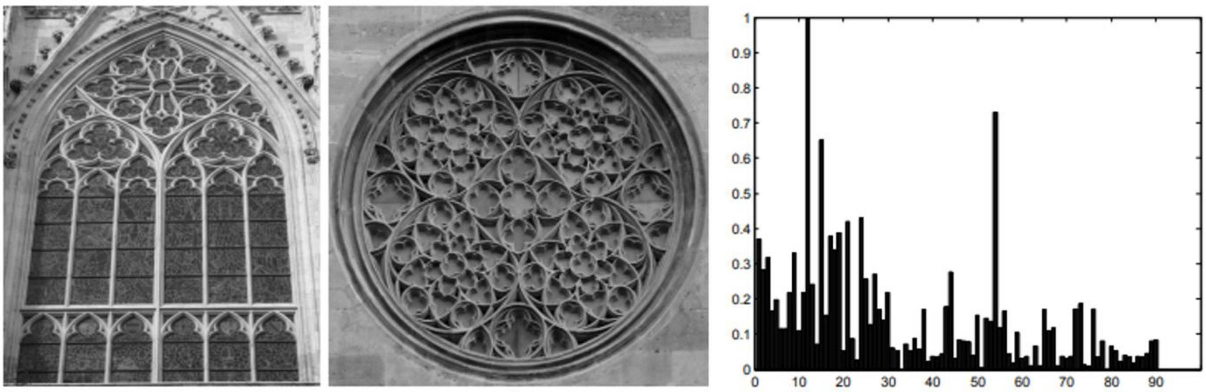

Fig. 4. Classification of architectural style according to window element, Gothic style example (Shalunts, Haxhimusa, & Sablatnig, 2011).

Llamas et al. (2017) used image processing techniques to classify and evaluate architectural elements of cultural heritage structures. They developed a classification algorithm that can detect 10 different types of architectural elements: Apse, Vault, Dome (interior and exterior), Column, Gargoyle, Stained Glass, Altar, Flying Buttress, and Bell Tower. With this study, the researchers presented a tool that can be used in the analysis, evaluation and conservation processes of cultural heritage structures, and they created a publicly available digital dataset consisting of 10,235 visual data, called the Architectural Heritage Elements Dataset (AHE_Dataset). This dataset was later used in the study of Ćosović and Janković (2020) for the digitalization of cultural heritage. The researchers worked with two different datasets using the same methodology. The first one is the Architectural Heritage Elements Dataset mentioned above, while the other one includes 5 categories of this dataset, namely bell tower, stained glass, vault, column, external dome (Ćosović & Janković, 2020).

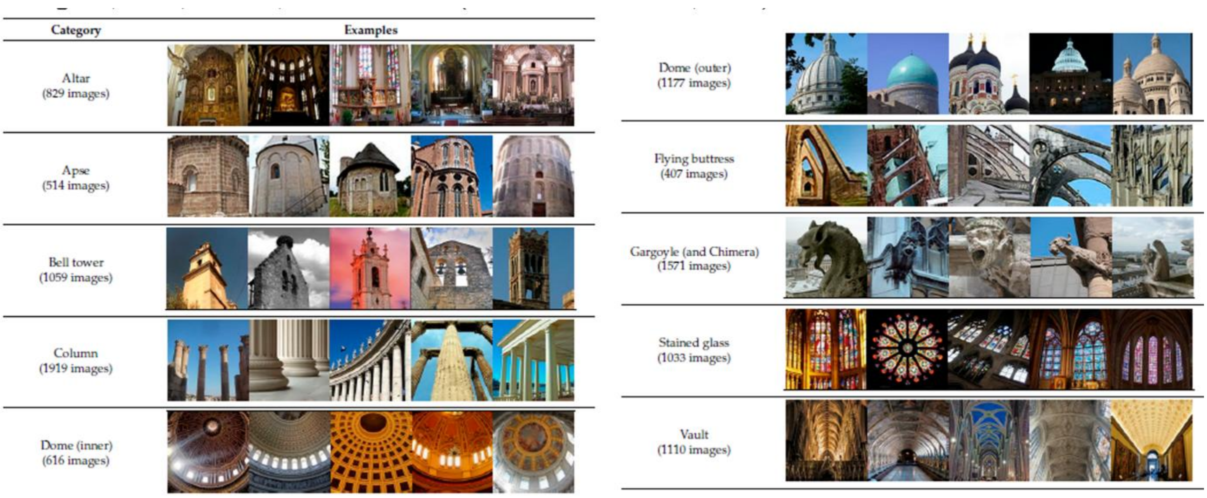

Fig. 5. Architectural Heritage Elements Dataset (AHE_Dataset) created within the scope of the study (Llamas, Lerones, Medina, Zalama, & Gómez-García-Bermejo, 2017).

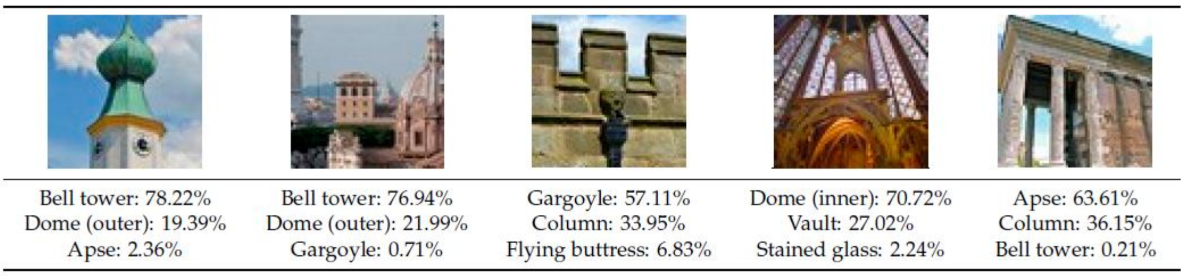

Fig. 6. Examples of predictions of the algorithm for given cultural heritage items (Llamas, Lerones, Medina, Zalama, & Gómez-García-Bermejo, 2017).

MonuMAI is an application that uses image processing algorithms to obtain architectural information from monumental building images. The application performs architectural building element detection, style classification and holistic monumental building definition. When MonuMAI users upload an image of any building facade to the system with this application, they can access various data about the structure. In this way, it has been demonstrated that cultural heritage awareness can be improved with an automatic system that can obtain monumental architectural information with a single visual data (Lamas, et al., 2021). Unlike other studies, MonuMAI is an application that the public can access and use in daily life to obtain architectural information.

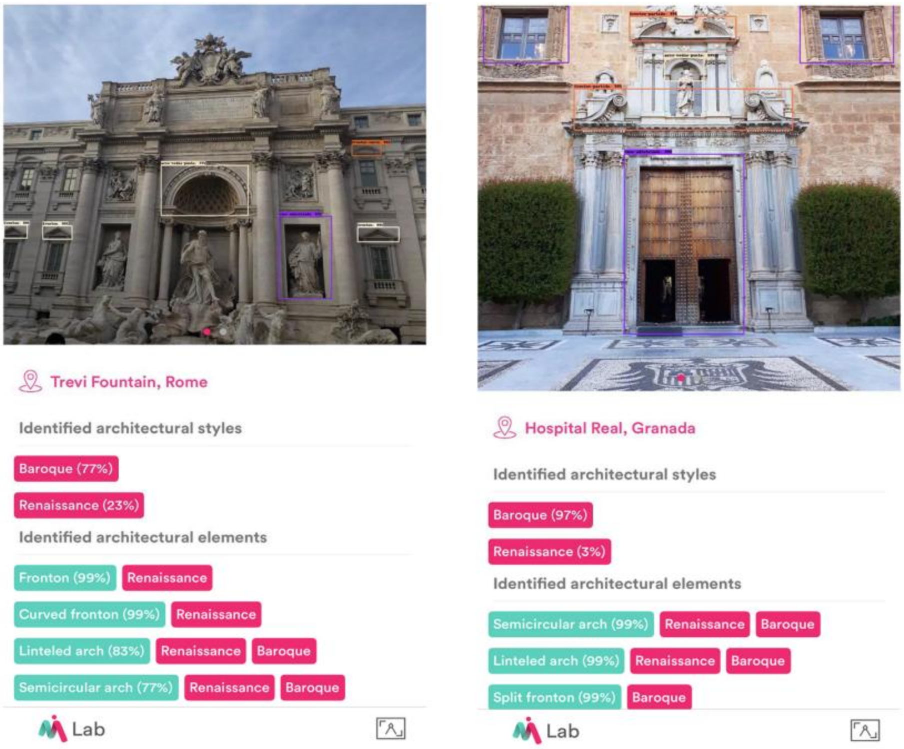

Fig. 7. MonuMAI application examples (Lamas, et al., 2021).

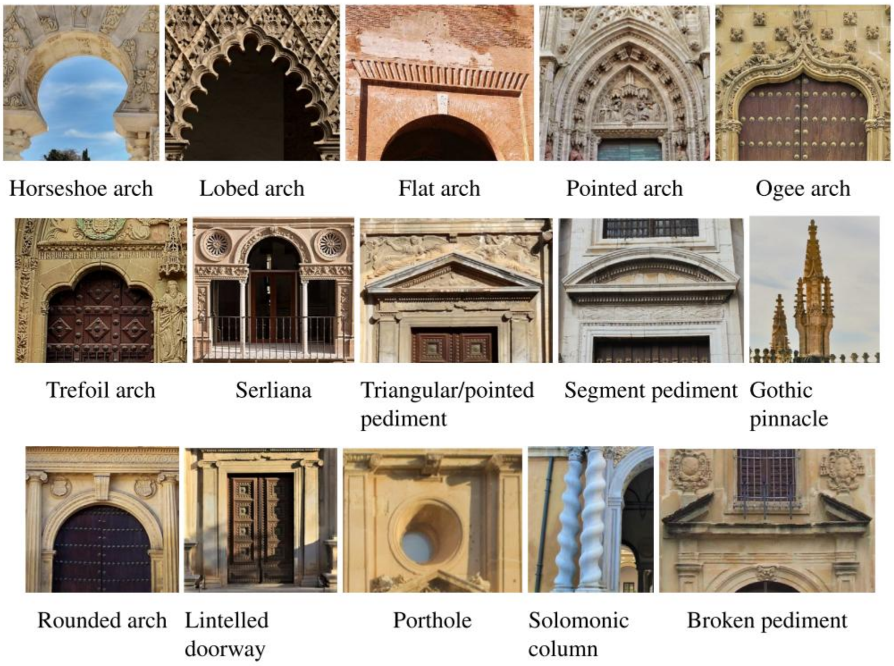

Fig. 8. The MonuMAI app includes fifteen architectural elements used to define Gothic, Renaissance and Baroque styles (Lamas, et al., 2021).

An example of AI language models used in documenting and ensuring sustainability of cultural heritage was carried out for the Gynasium structure of the Ancient City of Side. In the study, the Gymnasium structure was first documented using aerial photographs and laser scanning systems, and 3D models were created. Then, ChatGPT used to evaluate the results obtained. In this direction, articles and related examples about to the gymnasium structures, the ancient city of Side, and ChatGPT was requested to prepare a report referring to the examples but independent of them. At the end of the process, ChatGPT presented technical information consisting entirely of its own independent evaluations and all of which were correct. In the study, it was stated that ChatGPT and similar AI models have serious potential in documenting cultural heritage, transferring it to future generations, and ensuring its sustainability (Yurtsever, 2023). Another study offers an approach to developing cultural heritage field experience using the GPT-4 model, the most up-to-date version of OpenAI in that time. In the study, a digital guide called "MAGICAL" was created using the GPT-4 model in its infrastructure. The aim of MAGICAL is to establish a dialogue with visitors in museums or cultural heritage sites, to offer a route suggestion based on the feedback received from visitors, and to enrich the visitor experience by creating narratives on the relevant subject. Visitors can communicate with the MAGICAL digital guide by using natural language and speech without writing or reading any text. In this way, visitors can get information without losing visual contact with the exhibited cultural heritage object. One of the advantages of the digital guide is that it provides multilingual support. Visitors can change the language at any time, and the digital guide can answer in the language asked. Another advantage is that MAGICAL can change the speaking style depending on the age of the visitor. With all these advantages, visitors can have a personalized experience and can obtain information (Trichopoulos, Konstantakis, Caridakis, Katifori, & Koukoul, 2023). It is clear that the experience of the museums and cultural heritage sites can be enriched with language models with similar applications.

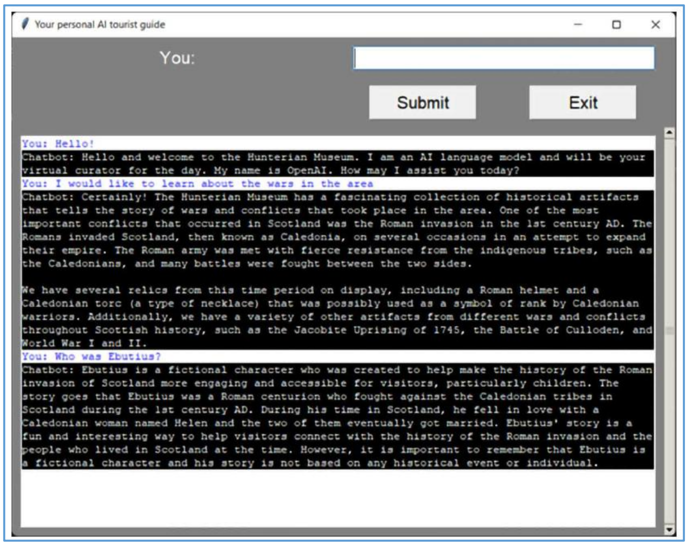

Fig. 9.MAGICAL test implementation using GPT-3.5 (Trichopoulos, Konstantakis, Caridakis, Katifori, & Koukoul, 2023).

Another example is the chatbot study that aims to create context-aware dialogue. In the study using the Multimodal Big Language Model, visual data containing cultural heritage artifacts were considered and the system was specially trained for cultural heritage sites. A training set consisting of 500 thousand visuals and 6.5 million question-answer pairs containing cultural assets such as archaeological findings, paintings, and sculptures was studied. The system uses the information in its infrastructure to answer questions about cultural assets. The questions were categorized as visual, contextual, and mixed, and the system was provided to learn the historical context as well as perceiving visual data. The chatbot approach presented in the study is a tool for understanding cultural assets in cultural heritage sites such as museums and archaeological sites, as it can work integrated with visual data and interact with the user to answer relevant questions (Rachabatuni, Principi, & Bertini, 2024).

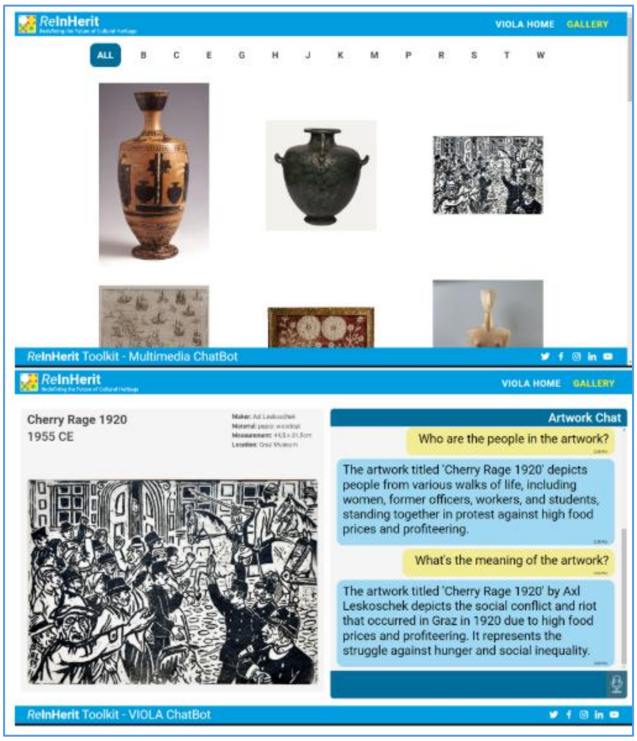

Fig. 10. Chatbot usage example (Rachabatuni, Principi, & Bertini, 2024).

4. Expected Contributions and Conclusion

The system proposed within the scope of the study provides a proof of concept model for enriching the visitor experience in cultural heritage areas with a focus on archaeological sites. The model, shaped within the framework of Dewey's theory of experience, aims to provide interactive, customizable and multi-sensory content for cultural heritage. In this context, this model can be considered as a step taken for alternative applications to traditional methods that can be developed for application in cultural heritage sites. It is clear that the study will restructure the "place" within a framework nourished by experience design, focusing on tangible and intangible values, and will contribute to the field experience as an original and intelligent system that will allow visitors to experience it emotionally in an immersive manner in the context of understanding, meaning and interpretation focusing on narratives and sub-narratives in different contents. At the same time, this study will create awareness for both application development and scientific research, and will form the basis for future studies. The study also presents a multidisciplinary and interdisciplinary research, and considers together the components such as methods, approaches, processes and the body of information they provide, fed by different disciplinary frameworks. In this context, the intelligent information system proposed for the presentation of cultural heritage in the disciplines of architecture, computer science and archaeology presents a new model and method with its originality. The study also brings a new and quite comprehensive data set for the Classical Architecture elements it focuses on to the literature. It is expected that all these findings and the data set created will form the basis for studies to be developed in different disciplines and different focuses. The system presented has the potential to transform the way we interpret and understand cultural heritage experience. It is expected that the personalized, interactive and on-site sensory experience it offers will allow visitors to spend more time in the area, enjoy the experience and trigger their next experiences. This situation is believed to play an important role in raising awareness of cultural heritage and ensuring its sustainability.

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An artificial intelligence aided design process from text to 3D printing

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Abstract. The rapid development of artificial intelligence in production systems is providing a significant transformation in architecture and design disciplines. The integration of artificial intelligence technologies, text-to-image generation, 3D modeling and digital fabrication processes opens up new possibilities in architectural design and production processes. The aim of this study is to reveal the transformation created by artificial intelligence in architectural design and digital fabrication processes and to discuss this transformation through an implementation process from design to production.The study aims to discuss the design process update on the impact of artificial intelligence on architectural design processes. This design process is planned in seven stages: programming, data collection, analysis, synthesis, evaluation, development and communication. These stages were compiled as a result of literature research. The equivalents of the stages of the design process determined within the scope of the study will be discussed in the design process aided by artificial intelligence. The effect of artificial intelligence on this process, which starts with the generation of the first ideas and goes up to production with digital fabrication, will be aided by an applied example. The process progresses from text to visual, from visual to 3D and from 3D printing to the final product. Thus, the positive and negative aspects of the integration of artificial intelligence into the architectural design process, the role of artificial intelligence as a designer and the potentials it creates in the design process will be discussed.

Keywords: Artificial intelligence; Digital fabrication; Design process; 3D printing; Text to fabrication

1. Introduction

Nowadays, artificial intelligence (AI) technologies are rapidly developing and progressing by constantly updating themselves. These developments in the field of AI affect not only the field of software but also fields such as art, design and architecture. Especially in recent years, the fact that AI technologies have become accessible to almost every individual with an internet connection expands the usage area of these technologies and enables new experiments. At the same time, the widespread use of generative AI tools such as ChatGPT, DALL-E, Midjourney, and Stable Diffusion has facilitated the development and public release of many similar tools, particularly those focused on text-to-image generation. On the other hand, the discipline of architecture has historically been influenced by technological advancements, with each new development bringing significant changes to design and construction processes. In this context, the advancement of AI technologies has opened up a wide range of applications in the field of design, from the emergence of new design methods to the optimization of production processes, and even to the simulation of human behaviors. (Leach, 2022). In particular, the recently widespread generative AI tools, with their capabilities in text-to-image and text-to-3D generation, have also been utilized in architectural studies. However, it has been observed that these applications often remain at the stage of image or 3D model generation. (Petráková & Šimkovič, 2023; Radhakrishnan, 2023; Doumpioti & Huang, 2023).

This study aims to rethink the traditional design process, introduced by Bruce Archer (1964) and Erdem Aksoy (1975) through AI-aided design processes. In this way, it seeks to establish a systematic approach to AI-aided design. The AI-aided design process conducted by text-to-image and text-to-3D generation processes. The final 3D product is produced with 3D printing tools. In other words, the study experinces to start from text input, create images and 3D models through generative AI tools, and ultimately produce a physical product within the scope of additive manufacturing, while also analyzing the process (Fig. 1).

To ensure a more systematic approach, it has been decided to base the planned process on a traditional architectural design process. The process, which begins with a textual command, progresses systematically by linking the mentioned design steps at each stage, ultimately concluding with the creation of a physical final product (Archer, 1964; Aksoy, 1975).

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2. The Method of The Study

In the design process developed within the scope of this study, the stages of the design models proposed by B. Archer (1964) and Erdem Aksoy (1975) are used as the base of the study. In both design processes, the stages of data collection (information gathering), analysis, synthesis, and development are commonly present. While B. Archer (1964) includes a "development" stage following the "synthesis" phase, E. Aksoy (1975) inserts an additional "evaluation" stage between these two phases. Moreover, Archer defines the first stage as "programming," whereas Aksoy identifies it as "problem identification." At the final stage, Archer adds an extra step: "communication." The new design process, which results from the integration of these two models, is illustrated below.

- Programming
- Data Collection
- Analysis
- Synthesis
- Evaluation
- Development
- Communication

These traditional design process steps are carried out within the AI-aided design process through the stages of text (prompt), image, 3D, and fabrication (Fig. 2).

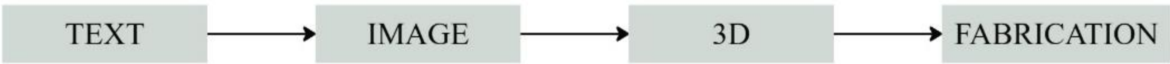

Fig. 1. Text-to-Fabrication Workflow

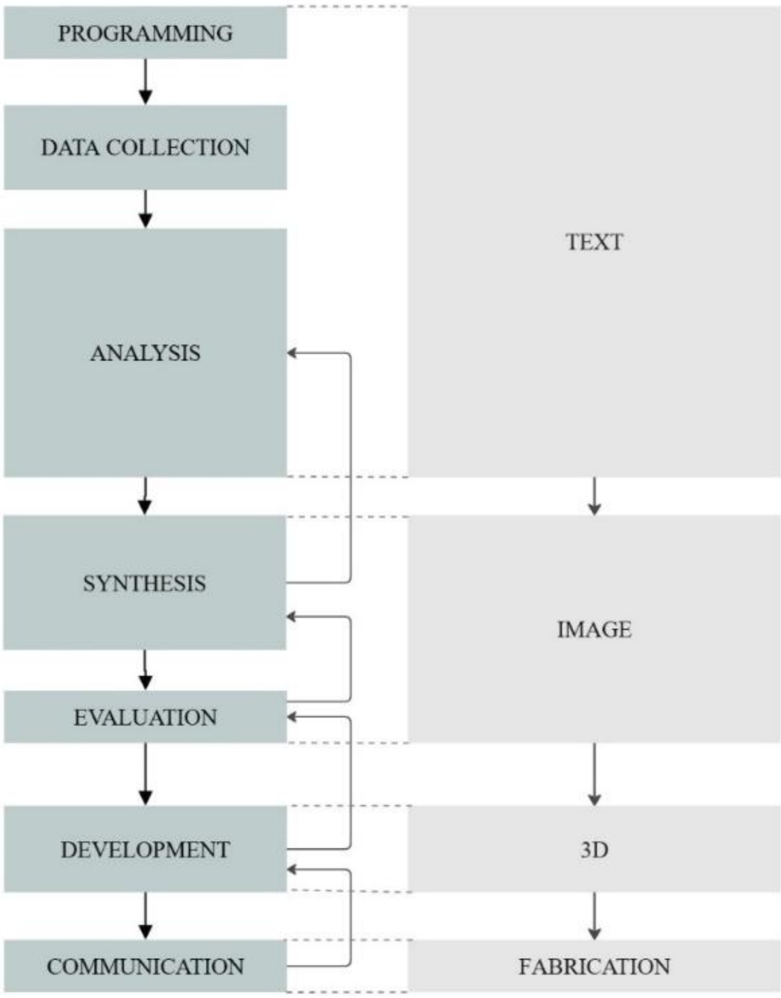

Fig. 2. The production process based on the traditional design process.

The design process begins with determining the output path and concept of the production. In this context, textual commands are defined. To transform these commands into visuals, an AI tool operating in a web platform called "Dream Studio" is used. At this stage, alternative visuals are produced and selected based on their suitability to the concept. The chosen visual is then transformed into 3D in STL through a web platform “3dp.rocks”. In the final step, the resulting 3D model is used to produce the final product with the help of a desktop 3D printer.

3. AI – Aided Design Process and 3D Printing

The details of the process developed in accordance with the design method referenced in this study are explained below:

3.1. Programming

Programming, the first stage of the design process, is defined as the identification of key issues and the creation of an action plan. In this stage, the output path and concept of the product to be designed are determined. This stage also serves as an initial step through its effective data collection within a specific framework. During the programming stage, conversational AI tools such as ChatGPT can also be utilized while developing ideas. In this context, the use of AI in stages other than visual production can be beneficial in terms of the diversity of the output. In this study, the concept has been defined as "the styles of famous architects or artists." The aim is to create a surface design based on the styles of architects and artists with the help of AI.

3.2. Data Collection

After the concept has been defined, the process moves on to data collection. This stage is defined as the process of gathering, classifying, recording, and transforming data into usable information (Bayazıt, 1968; Archer, 1984). Within the framework of the defined concept, textual and visual data are obtained from various sources. The quantity of data in this stage is important for the diversity of the production, as it allows for variation in the command generation process. Since a feedback-driven process is applied in this study, experiences from later stages can also enrich this phase. In this stage, data has been collected regarding famous architects and artists with more characteristic styles, such as Zaha Hadid, Daniel Libeskind, Vincent Van Gogh, and Picasso, within the framework of the defined concept. Once the collected data reaches a sufficient level, the process moves on to the next stage.

3.3. Analysis

The analysis stage can be defined as the process of simplifying data through observation and experimentation or transforming design requirements into meaningful and functional characteristics (Jones, 1992; Aksoy, 1975). This stage is where suitable words or word groups are determined to create commands that will be used in the visual production of the data obtained during the data collection process. The main goal of this stage is to create a word pool for the diversity and updating of the commands that will be used to generate visuals from text using AI. Visual contents can also be gathered at this stage; however, in this study, only textual commands were used. In this context, words such as "surface, style, design, architecture, monochrome, abstract, texture, inspire, Zaha Hadid, Daniel Libeskind, architectural surface," etc., were generated. Once the generated words reach a sufficient level, this stage is completed.

3.4. Synthesis

The synthesis stage is defined as the process of combining different variables to produce new solutions and integrating these partial solutions into a whole. It is also the stage where creativity is most involved, and design ideas are developed (Aksoy, 1975; Archer, 1984). In this study, this stage is considered as the phase where the words determined in the analysis stage are combined to create commands that will be used in the AI tool, and visual productions are made using these commands. In this sense, while the conversion of the obtained data and words into commands is related to human creativity, the ability to generate various visuals from the determined commands is related to the creativity of AI.

In this context, the creativity of AI can be associated with the data it was trained on during its development. Therefore, different AI tools can produce different visual outputs for the same commands. In this study, only one AI tool was used. Since a feedback-driven process is implemented, the outputs in this stage are evaluated, allowing the commands created in the analysis stage to be updated and improved. The visual diversity in this stage is important for visual selection, both in terms of suitability for the purpose and manufacturability.

In this study, DreamStudio, an AI tool operating on a web platform, was used for visual production. DreamStudio allows users to create visuals by defining scenes, characters, or concepts with text descriptions. Using the words identified in the analysis stage, visuals were produced in different styles. While producing the visuals, words such as "monochrome" or "surface design" were used for both ease of transfer to 3D and production convenience. This approach aimed to generate visuals with contrasting colors (especially black and white), as distant as possible from the perception of three-dimensionality (Fig. 3).

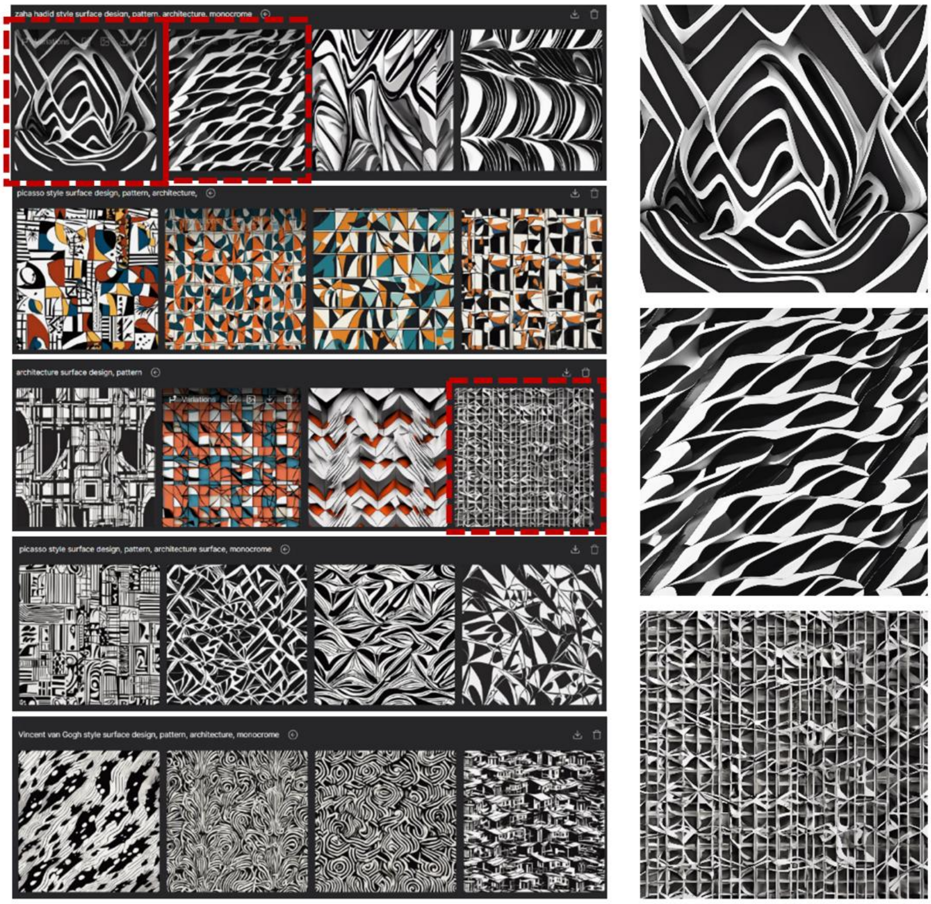

Fig. 3. The visuals obtained from the DreamStudio AI tool with the generated commands

3.5. Evaluation
In this stage, the visuals are evaluated in terms of their suitability to the concept, transferability to 3D, and manufacturability, and a selection is made for the next step. During the transfer to 3D, it is important for the visual to be simple, free of excessive details, and to have contrasting colors in order to ensure a smoother production process (Fig.3). Specifically, choosing visuals with less light and shadow effects, and a more two-dimensional perception, helps the 3D model form more clearly. On the other hand, some of the AI-generated productions may differ from the concept or the input command. Within the framework of all these criteria, three visuals that reflects the concept and is more manufacturable was selected, and the process continued.

3.6. Development
This is the stage where the visual selected during the evaluation phase is transferred into three dimensions and further developed. This stage was carried out using two different methods. In the first method, one of the selected visuals was directly converted into three dimensions as raised patterns on flat and cylindrical surfaces with the help of the web-based tool “3dp.rocks”. The software performs this process by creating a depth map based on the tones of the colors in the visual, thus generating depth. Each color value in the image is mapped to a numerical height value, and points are generated at these heights. This point cloud is then transformed into surfaces through triangulation, resulting in a "mesh model." With the help of such software, visuals can also be applied onto different geometric forms, such as cylinders, spheres, or curved surfaces. As a result of this method, STL-format 3D models of the designs were produced on one flat and one cylindrical surface (Fig. 4). In the second method, the other two obtained visuals were used. This method aimed to create structural forms with a perforated structure. For this purpose, the surface visuals obtained in the previous stage were first uploaded to the ChatGPT tool, and 3D visuals of these images applied to cylindrical and hemispherical forms were requested (Fig.5). The obtained visuals were then converted from image to 3D using the web-based tool “meshy.ai.” As a result, one STL-format 3D model in cylindrical form and one in hemispherical form were generated for each of the two visuals (Fig. 6).

3.7. Communication

The final step of the process, communication, can be described as the stage where the design—along with its purpose, functioning, and details—is conveyed to the producer, user, or evaluator in a clear and effective manner (Aksoy, 1975; Archer, 1984). In this context, it represents the stage where the final product is achieved. Productions carried out with continuously advancing AI technologies often conclude in the creation of visuals or 3D models. Therefore, it is crucial to materialize the final product using digital fabrication methods. In this stage, the simulation of the 3D model, achieved in STL format during the development phase, was examined using a slicing software designed for 3D printers (Fig. 7). Among the final products, the model created using the first method was selected, manufactured with a desktop 3D printer using PLA material, and the resulting outcomes were obtained. (Fig. 8).

Fig. 4. STL format flat and cylindrical models obtained using the "3dp.rocks" tool.

Fig. 5. Forms of 3D visuals generated through the ChatGPT tool.

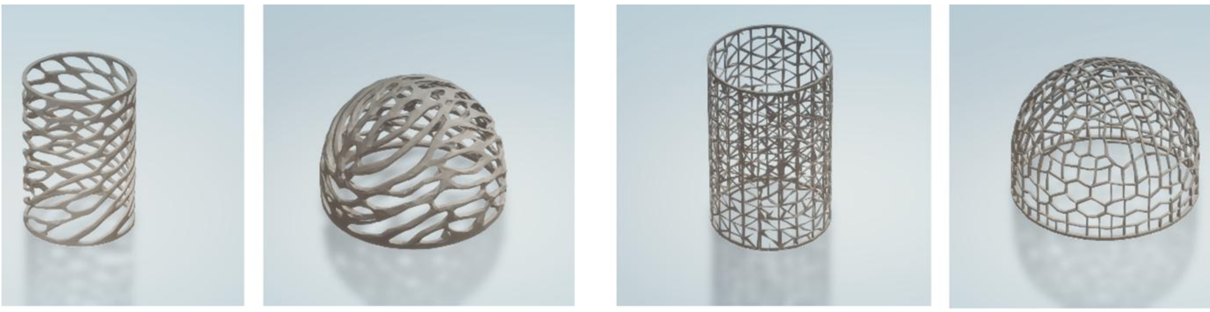

Fig. 6. STL format 3D models obtained through the Meshy.ai tool

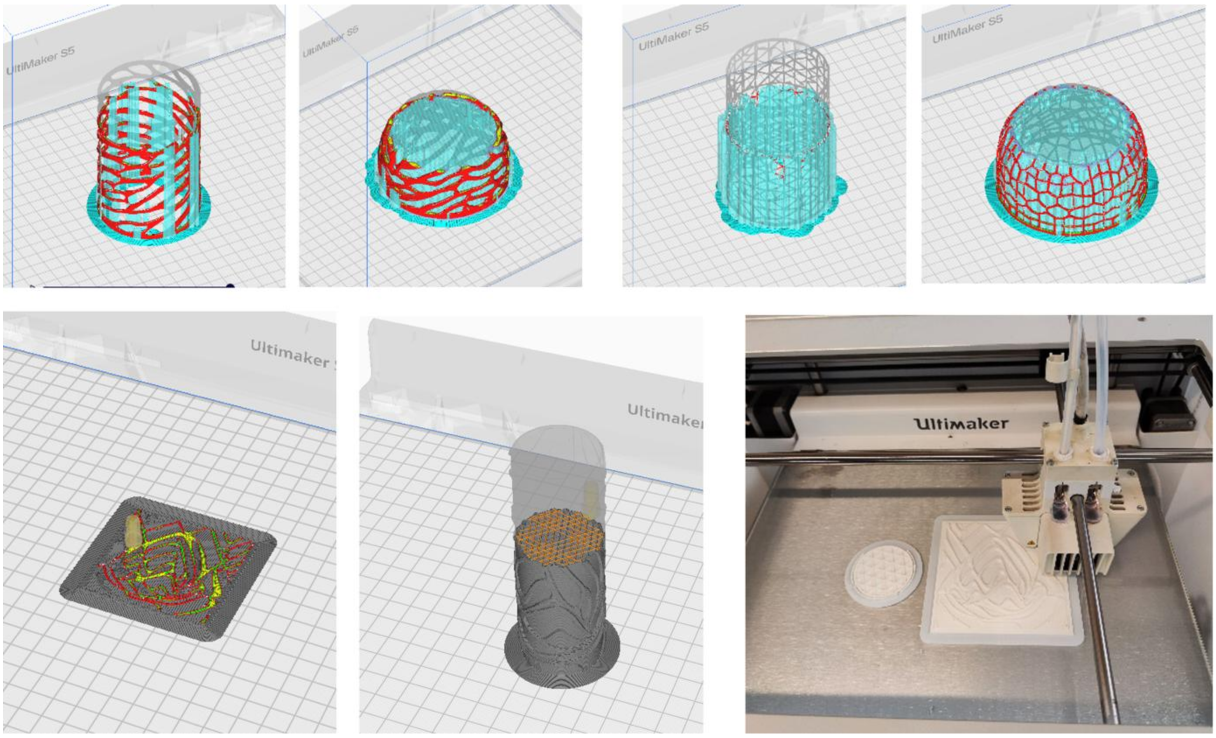

Fig. 7. Desktop 3D printer simulation and additive manufacturing process

Fig. 8. Final products

3. Results and discussion

In this study, the "text-image-3D-printing" process was developed into a more systematic model, based on a traditional architectural design process. The steps in the process, extending from text to fabrication, were related to the stages of "programming, data collection, analysis, synthesis, evaluation, development, and communication". In this context, the design process began with the goal of creating a surface design based on the characteristic styles of famous architects and artists. Within this framework, data was collected and key words were generated. Using the created keywords, various commands were produced, and these commands were visualized using an AI tool that generates images from text. The resulting visuals were evaluated for their suitability in manufacturing with a 3D printer, and one that was considered appropriate was selected. Since the visuals are transferred to 3D using a depth perception method based on color tones, in this stage, visuals that are free from excessive complexity, generally containing no more than two tones, and lacking a 3D perception were taken into account. Additionally, for visual productions that did not meet these criteria during the process, improvements were made in terms of command-output visual relationships through command adjustments. The selected visuals were transferred to 3D on flat and cylindrical surfaces using a software tool operating in a web environment. The created 3D models were produced with PLA material using a desktop 3D printer, and the final product was obtained.

This study also dicusses an AI-aided design process that extends from text input (prompt) to additive manufacturing within the context of the rapidly evolving potential of AI technologies in architecture. In a period where AI-generated visuals and 3D productions have become widespread, advancing this process one step further by concluding it with a physical final product is considered valuable. Within the scope of this study, the production criteria for designs that originate from text prompts and are transformed into 3D models through visual generation are evaluated using a 3D printer. Through the feedback-oriented process established in this context, solutions are proposed to address encountered and potential problems, thereby enhancing the overall production process.

As a result, the rapidly advancing AI technologies' abilities to produce visuals and three-dimensional objects hold significant potential for the field of architecture. In this regard, the study discusses to provide solutions to the challenges of how design can be brought to life by taking productions a step further from the third dimension. These rapidly evolving technologies are continually enhancing creativity and the ability to diversify production. In this study, a surface design with more defined boundaries has been addressed; however, with the development of AI tools capable of producing both visual and three-dimensional outputs, it is anticipated that different production potentials will emerge, particularly in the fields of architecture and design. At the same time, with this design process, the potential for producing a variety of outputs using subtractive, formative, or joining-based digital fabrication methods with different materials is considered highly valuable. In this regard, the insights gained are anticipated to provide a methodological foundation for future research.

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Place-specific structures: The effect of hidden designs on the spirit of space

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Abstract. In an era where the meaning of architecture in relation to place has diminished, globalization and rapid urbanization have given rise to monotonous and identity-lacking structures. Designs that fail to grasp the importance of the spirit of place create spaces that are disconnected from their surroundings, turning them into closed boxes -essentially inward- focused spaces. Architecture confined to a specific design type not only weakens its own identity but also diminishes the essence of the place it occupies, leading to cities that lose their character. Structures that fail to establish a connection with their location are seen as designs that lack harmony with their surroundings and the topography they inhabit. These buildings hinder the sense of belonging to a place, compromising the quality of life for their users. However, in architectural design, "place" holds a crucial position. Place, regarded as a primary element in architecture, is the foundational component around which design is shaped. While the concept of place is an empty space that exists in relation to itself and its surroundings, the inclusion of architecture transforms it into a meaningful spatial whole by creating harmonious relationships. In this context, creating region-specific designs serves as a bridge that strengthens the relationship between users and place. Designs imbued with originality make the environment more visible and legible, thereby enabling the preservation of the spirit of the place or topography. Structures that integrate the characteristic features of the area into their designs aim to make architecture a part of the topography, creating structures that are integrated with nature. Designs that are embedded within the topography adopt the environmental, physical, and social characteristics of the place, contributing to environmental sustainability. These designs also reflect the lifestyles of the community onto architecture, fostering a sense of belonging to the place. A design approach that respects the collective memory of the community simultaneously preserves cultural heritage. In this context, this study examines place-specific design approaches and evaluates architectural designs integrated with the topography. The selected designs are chosen from the ArchDaily web database. The compiled structures are discussed in terms of design criteria such as aesthetic and functional features, sustainability, and place-specificity. It is anticipated that the discussions carried out on individual structures will shed light on future architectural design approaches, contributing to the creation of unique urban spaces.

Keywords: Topography; Originality; Context; Spirit of place structures

1. Introduction

First and foremost, architecture starts with 'place' and exists together with it. While the place establishes the architecture, the architecture should also be able to transform the place. Architectural design becomes meaningful as long as it harmonises with the place. The place, which plays a decisive role in architecture and makes the building a meaningful whole, gains meaning again with the previous formation in every relationship established with it and establishes a relationship with it (Kuyrukçu & Alkan, 2019). 'Place', which can only be formed when a meaningful relationship is established with the environment, gains meaning by integrating with the lives it harbours and the elements around it. Thanks to the meaningful relationships it creates, the place goes beyond mere space and opens up to 'relations' and 'actions' that are realised through users (Berber, 2011). In this respect, it is necessary to expand the interpretations of space to understand a place and to understand that urban spaces depend on daily lives, experiences and collective memory. It is important that architectural designs in the place respond to people's sensations, make them feel a sense of belonging to that place and respond to their needs (Özcan & Güngör, 2019). Norberg-Schulz defines architecture as the abstraction of the spirit of the place; 'Architecture is for designing meaningful places'. Schulz attributes the human tendency to design places to three phenomena: 'revealing the meanings hidden in nature, revealing the meaning of nature, and boasting that they have created by

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designing what does not exist’. He says the main reason underlying these is ‘man's desire to create a small universe of his own’ (Kaymaz Koca, 2005). Since ancient times, man has endeavoured to change and mould the earth to fit his own image of it.

The relationship between place and topography is very important in creating meaningful spaces on earth where human beings try to create a universe of their own. Topographic structure is an important phenomenon that designers should consider. The topography of the place consists of a dynamic and fluid structure that is naturally and culturally open to human influence. This structure is articulated on urban layers such as ‘form, texture, urban planning and architectural history’. In cities; every event such as physical, social, cultural and economic elements leaves a trace on the geographical structure. With each trace left, the phenomenon discussed in terms of topography ceases to be only land and creates new geometries, surface forms and layers with new additions (Köse, 2010). Artificial traces, which are decisive on the physical topographic surface, depend on the life cycle established on it, such as how much diversity the human impact on the ground, how much it blends with time and how active daily life is (Küblü, 2015). However, architectural structures that have human touch and exist on the topography leave artificial traces on the earth.

According to this context, it is possible to say that ‘structures’ and ‘place’ should be considered whole. Within this unity, the topographic layers of the city and the structures can be expressed as complex, intertwined and in conflict with each other, tense unions that continue with the transition from natural to built. This tension between the layers brings along the dynamism of the city. This dynamism can be defined as a different dynamism far from the state of equilibrium, undergoing unique metamorphoses, and subject to intense flows. Thus, the buildings that continue to exist on the land, over time, integrate with the surface on which they are located, interact with their physical environment, and define the ‘urban topography’ by taking a constantly changing form (Küblü, 2015; Fig. 1).

In the formation of urban topography, the formation of the topography is important. Different topographical forms bring along different space formations and create the unique structure of the city (Saçık, 2018). In this context, the creation of architecture with design approaches that are compatible with the place, can be hidden in the natural texture where it is located and are environmentally sensitive, will ensure the protection of the original stance in cities (Fig. 2).

Structures integrated with the topography create useful spaces by providing a strong indoor and outdoor connection. The approach creates sustainable living spaces integrated with nature, while at the same time enriching the user experience by strengthening the interaction with the landscape (Fig. 3).

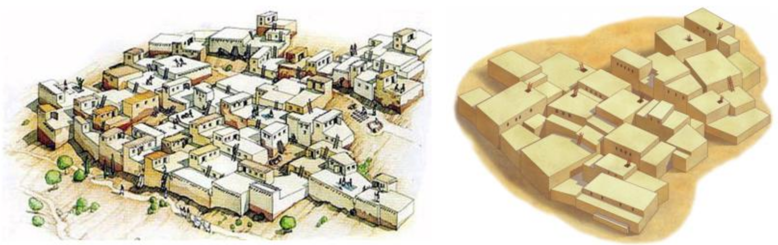

Fig. 1. Integration of Çatalhöyük houses with the city (URL 1; URL 2)

Fig. 2. The topographical layout of Villa D'este, hidden in the natural landscape (Desnoyers, 2015; URL 3)

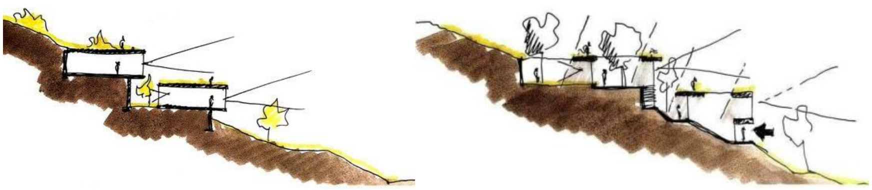

Fig. 3. Landscape interaction of topography-specific structures (URL 4; URL 5)

The buildings are in harmony with the local ecosystem as they are designed by considering criteria such as climate, orientation, temperature and the diversity of living organisms/flora specific to the place. The building also provides energy efficiency by utilising natural ventilation and daylight (Fig. 4). When site-specific design approaches are evaluated as a whole, they also increase urban resilience. These buildings not only harmonise with the environment but also consider the cultural and historical context of the locality. The use of local materials and traditional construction techniques in the buildings acts as a bridge between the past and the future.

Wells states, ‘Buildings created with the understanding of gentle architecture will give life back to the place where they are located instead of stealing life from it. These structures, which provide users with safe and psychologically revitalising environments, resemble nature itself.’ (Heffner, 2013; Fig. 5). In this context, site-specific buildings are design approaches that provide environmental sustainability by integrating the forms and characteristics of the nature in which they exist into architecture. These buildings become a part of the natural landscape by protecting and observing the slope and character of the area. At the same time, the design concepts reinforced with green roofs and placed under the ground make the building feel like an extension of the environment. These designs contribute to the deepening of the spirit of the space by giving the users the feeling that they are part of nature. Hidden designs aim not only to build a structure but also to create a dialogue between the natural and artificial environment.

Adapting to the natural slope during the placement of the building minimises the intervention to the land by minimising excavation and filling operations. Thus, natural drainage is preserved and the building is integrated with the topography. In addition, layout strategies that are parallel to the slope or staggered increase the view opportunities and make the best use of natural ventilation and sunlight (Fig. 6). The choice of materials and the design of the building envelope should also be determined to adapt to the microclimate conditions offered by the topography. This not only ensures energy efficiency but also supports the longevity and sustainability of the building.

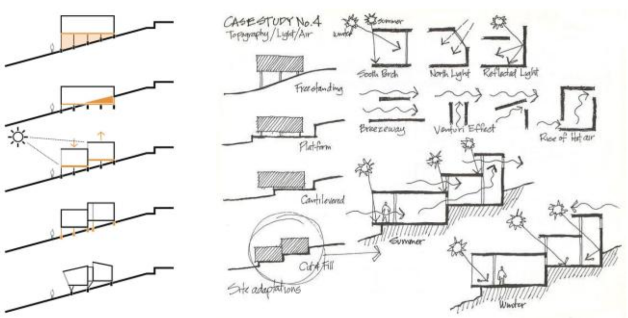

Fig. 4. Natural ventilation and daylight efficiency in site-specific design approaches (URL 6; URL 7)

Fig. 5. Satellite image and sketch of Cherry Hill Office with its gentle architectural approach (URL 8; Wells, 1998)

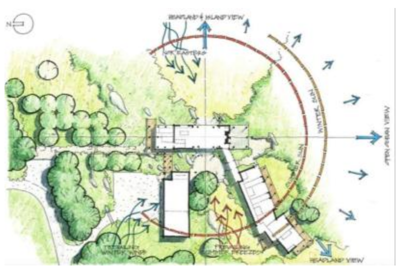

Fig. 6. Natural ventilation/lighting possibilities in slope-appropriate layout (URL 9)

In site-specific designs, the way of positioning the mass is differentiated according to the function of the building and the slope of the topography. This differentiation is within the scope of strategies to increase energy efficiency while ensuring the harmony of the building with the environment. The change of settlement patterns is also realised to increase the comfort of the users. There are six different massing types within the scope of adaptation to the terrain (Fig. 7).

1.1. Terracing and console
The terracing method created on steep terrains allows for natural lighting in stepped building designs, while at the same time providing a view by establishing a relationship with the environment. The levelled masses created in the building also allow for terracing and outdoor designs. The console designs offer a good planning method to complement the slope. This concept helps to protect the slope while creating more space for the spaces. It also creates an aesthetically pleasing visual appearance (Kader & Kupik, 2011, Fig. 8).

1.2. Cut and fill
An important technique for adapting to sloping or uneven terrain, the cut-and-fill method is essentially the process of carving a plinth to build a house designed for use on flat land. The pieces cut from the terrain were reused to create the levels at the lower edge (URL 11, Fig. 9).

1.3. Columns
Column designs eliminate the need for expensive foundations, reducing the negative effects of moisture and allowing natural ventilation. These designs enable planning without touching the natural ground and without damaging the environment. In addition, the mass rising from the columns protects the natural environment and allows wildlife to thrive underneath the structure (URL 11, Fig. 10).

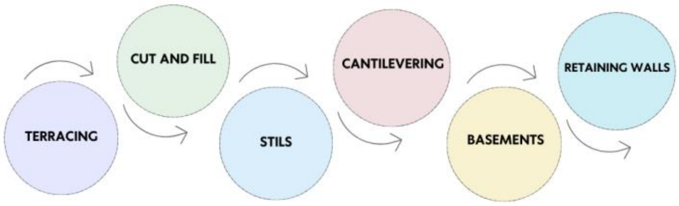

Fig. 7. Types of terracing on slope

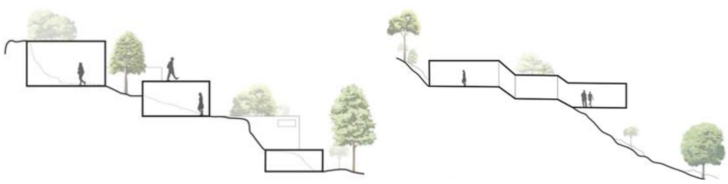

Fig. 8. Terracing and console design (URL 10)

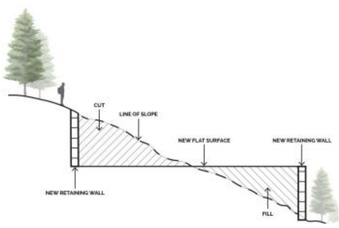

Fig. 9. Cut and fill (URL 10)

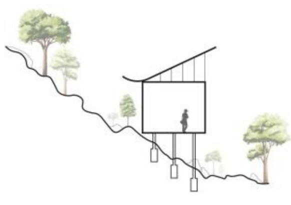

Fig. 10. Columns

1.4. Retaining walls and basements

On sloping terrain, masses that cut into the site are a useful technique for managing the degree of slope and preventing the risk of erosion on the site. These designs also allow the creation of large spaces that open up to views. Another technique, designing the building completely under the ground, serves to protect the natural slope and creates an important factor for the continuity of the ecosystem on the site (URL 10, Fig. 11).

2. Site-specific building design reviews

2.1. Library in the Earth

Library in the Earth, a sustainable living and cultural centre located on an organic farm in Japan, was designed by Hiroshi Nakamura & NAP (Fig. 12). This futuristic design is built on a hillside, disappearing into the natural landscape and integrating into the environment with its cascading greenery. Unlike traditional typologies, the library structure is positioned around a slit-shaped courtyard resembling a water drop. In this hidden underground structure, cantilevered concrete slabs are used to create integrated spaces. The structural design choice allows the interior spaces of the library to blend organically with each other. The earth coverings in the spaces evoke a sense of unity with the surrounding earth structure. The ceiling heights are shaped according to the slope, creating low-ceilinged niches in the space. In the reading room, the heart of the library, an overhead skylight provides a serene view of the sky, while at the same time providing natural ventilation to the space (URL 12). While the project endeavours to blend nature with the building in the best possible way, it also embodies the philosophy of the library as a place of refuge.

2.2. Issa Megaron

The design philosophy of the Issa Megaron building, located in Croatia and planned by PROARH, is related to the solution of the context of the boundary perceived as a 'void' in the area (Fig. 13). The project consists of designing a temporary retreat house for a family. The building is designed with the philosophy of 'Genius Loci', the design concept of the Mediterranean region. In the house, ancient stone plasterboards are reinterpreted and harmonised with the region. The new/old stone walls create a symbiosis with the existing topography by using materials that subtly harmonise with the ground. The building, which is intended to give the effect of an artificial cave / excavated volume, uses sustainable design methods such as natural cooling/ventilation, solar panels, and rainwater utilisation. The materials used are renewable and adapt to the region (URL 14). The building, which disappears in the topography while at the same time harmonising with it, is a warm 'house' design that reflects the unique spirit of the Mediterranean region and matches nature.

Fig. 11. Retaining walls and basements (URL 10)

Fig. 12. Library in the Earth (URL 13)

Fig. 13. Issa Megaron (URL 15)

Fig. 14. UCCA Dune Art Museum (URL 17)

Fig. 15. Villa Aa (URL 19)

2.3. UCCA Dune Art Museum

Located on a quiet beach in China, the art museum was designed by OPEN Architecture (Fig. 14). The building, which has an extraordinary design with its appearance disappearing in the sand dunes, is inspired by the cave structures, which are the oldest settlements in human history. Hidden between the sea and the sand, this structure creates timeless spaces while prioritising pure and touching space design. Designed to be hidden, the structure respects nature while protecting the dune ecosystem that covers it. Composed of a series of cell-like spaces, the spaces accommodate galleries of different sizes. The complex three-dimensional geometry of the museum shell, which creates the effect of a secret sanctuary, intertwined with the body and soul, draws attention. The skylights of the building, with different orientations and sizes, provide natural lighting to the museum spaces at all times of the year. The sand-covered natural roof of the building greatly reduces heat loads and contributes to energy efficiency (URL 16). UCCA Dune Art Museum, which integrates with the sea and sand, continues its existence in the area where it is located as a structure that respects the ecosystem with its sustainable features.

2.4. Villa Aa

Villa Aa is an extension of a historic farm building in Denmark and is a 'house' by CF Moller Architects (Fig. 15). This invisible structure is shaped according to the nature of the site and opens up to the views of the region. The design aim of the villa is to integrate the office with the house. It is intended to create a flow and connection between work and home, thus preserving practicality and personal well-being. However, the south façade of the building opens up to the garden and the terrace that connects to the outside, allowing views of the site-specific landscapes. The spaces have skylights that provide natural light. The roof of the roof, designed as a green roof, harmonises with the area where it is located and at the same time serves as an upper terrace as a spatial function. The pool on the terrace establishes a visual connection with the existing water by reflecting the skylight. The choice of concrete used in the building is to respect the historical farm structure. The polished concrete used on the floor of the space continues to the outer terrace and is one of the design decisions to break the distinction between the interior and exterior (URL 18). All these design decisions connect Villa Aa to its location and the historical farm it is located in, while protecting and respecting its environment.

Fig. 16. Audemars Piguet Workshop Museum (URL 21)

Fig. 17. Ncaved House (URL 23)

2.5. Audemars Piguet Workshop Museum
The Audemars Piguet Workshop Centre for the Swedish watch brand was designed by BIG (Fig. 16). With a distinctive and innovative design in line with the company's philosophy, the building is planned in a spiral shape and in a concept that integrates with nature, with an ancient understanding of the area where it is located. The iconic, double-helix workshop centre is embedded in the topography, with a glass façade and a spiral shape. The pavilion is an urban landmark that reflects the company's watch designs, at the same time being timeless and sculptural in its landscape. The design concept, created by establishing a link between the building and the watch discipline, pays tribute to both the arts. The glass and metal materials used add movement to the identity of the building, while the curved glass walls are positioned to let the sun in. The spirals, which are the design philosophy of the building, are intertwined and interconnected in a way that guides visitors through the building. The spiral takes visitors through the spaces in a systematic order and finally leads them to the centre, the heart of the building. The heart of the building is the final destination of this journey, symbolising the independent and pioneering spirit of the company and its deep commitment to its origins (URL 20). The building expresses Audemars Piguet in its dynamic and intertwined form with its spiral design, while at the same time, it continues its existence with an understanding of continuity that will harmonise with nature in the landscape in which it is located.

2.6. Ncaved House
Located in a small bay on an island in Greece, Ncavedv House is a holiday home designed by Mold Architects (Fig. 17). The idea of avoiding the strong north winds in the region while at the same time dominating the landscape has created the need for the building to hide in the slope where it is located. Offering a spatial experience intertwined with nature, the building has a design that will announce its existence to its surroundings as well as its respect for the soil. The building design also protects the cultural heritage by reinterpreting the traditional behaviours of the region with the dry stone it uses. The raw material designs, such as stone, bare concrete, wood and steel in the building also intensify the feeling of living in a natural space. The roughness of the materials used together with the processed details create a warm and natural contrast in the spaces. With the front part of the building facing east, the rear windows opening to the inner gardens below the ground level provide natural airflow and natural light to the underground floors (URL 22). With the material and colour decisions used in the design, the building's feeling of an unprocessed, natural rock cavity and several active/passive planning decisions, a concept that is sustainable and connected to/integrated with the area where it is located has been put forward.

2.7. Felderhof House
Felderhof House, which is located in the unique nature of Italy and whose architecture was undertaken by Pavol Mikolajcak Architekten, is a building consisting of two single-type structures built by shifting to adapt to the slope

of the slope (Fig. 18). The existing farm building, which is unique to the valley slope where it is located, is an authentic representative of life in ancient times with its stone-dominated facade and wooden shingle roof. In this context, the building design is based on a balance between contemporary life and historical authenticity.

Fig. 18. Felderhof House (URL 24)

Fig. 19. Homescape House (URL 25)

Since the topography of the building is seen as a suitable land for underground design, a connection opportunity to the existing old building was also created. Almost completely hidden in the valley, the house offers a strong mountain view with its long glass facade extending to the south. The open space design, high ceilings and skylights of the house provide a high contrast to the closed and delicate texture of the existing historic building to which it is connected. The skylights offer views of the larch trees native to the region, while at the same time providing natural lighting and light play to the spaces. The materials used in the building, such as natural stone, exposed concrete, steel and wood, are in harmony with the surrounding landscape. The concrete used in the geometric ceiling bears the trace of the raised hill. The wooden furniture and classical surfaces of the dwelling take care not to disturb the original character of the preserved building (URL 24). The building, which shows how a historical building can be integrated with a modern residence, is in harmony with the region with its materials, building design and landscape dominance.

2.8. Homescape House

Homescape House, designed by MXarchitecture, is located on a high plateau on an island in Greece (Fig. 19). In the region where fruit and olive trees are grown, human interventions have been aimed at strengthening the spirit of the place without disturbing the area. The building, planned in an authentic environment, is a project in which it is desired to reveal the habitat together with nature. The design concept is to create a permeable spatial style in which nature and structure are interrelated. The design concept, where the common areas of the building are open to the landscape, continues with the adaptation of the living spaces to their surroundings. The service spaces are located at the underground level. Artificial and natural verandas provide natural comfort and lighting as well as multi-directional ventilation. Raw wood, red, white and black stones, marble and aluminium are the local materials of the area. While the openings provide sunlight to the spaces, the mass inertia of the mineral floor and stone walls provides a natural heating/cooling function that follows the day-night course (URL 25). Homescape House, with its defined mass and space distributions and the local and natural materials it uses, encompasses and integrates with nature without harming it.

3. Conclusion

Topography, which is one of the elements most affected by urbanisation among natural data, determines the design formations of cities and buildings to a great extent with the change of land structures. In this context, the topography of the area will reflect the natural character of the city. The more different movements the topography land, which has its characteristics, and harbours, the more differences and originality the city/building articulations to be built on it will harbour. This study, which aims to explain the essence and meaning of building plans hidden in topography, also consists of analysing some examples to comprehend the importance of site-specific designs. The projects examined in this context show that building designs that integrate with nature contribute to energy efficiency by minimising damage to the environment, integrating with the surrounding ecosystem, and becoming one with the space in which they exist. In this context, topography-specific design approaches can be seen as approaches where human impact will be the least visible in nature, will leave fewer traces in the original geographical structure, and are more compatible with the dynamic field structure. In the case of building designs, different topographic components inspire unique designs and enable new space formations. These design approaches will also contribute to indoor and outdoor connections that will add innovation and originality to the spatial contexts. In addition, designs that utilise natural data provide natural lighting/ventilation, wind isolation and landscape dominance. According to this context, it is thought that the sensitivity shown to site-specific design approaches and the continuity of these approaches will contribute to the formation of cities that are sustainable, in harmony with nature and people, and that do not damage the area where they are located and are at peace with it.

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Comparative research of historical and modern train stations in Türkiye in terms of scale, function and architecture

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Abstract. The history of railways and train stations in Anatolia began with the construction of the İzmir-Aydın railway and the first train stations, İzmir-Alsancak and Aydın Railheads, between 1856 and 1866, with the privilege given to the British during the reign of Sultan Abdülmecit. Especially after the proclamation of the Turkish Republic in 1923, 'weaving the country with iron nets' was seen as an important national goal. Train stations have been influenced by movements such as the First and Second National Architecture and modernism, which reflect the political and cultural situation, technological and economic development and expectations of the society of the period in which they were built. Since the 2000s, high-speed train lines and stations began to be planned in Turkey and in 2009, the Ankara and Eskişehir High Speed Train Stations have started to be used. Train stations of Turkey have been the subject of academic studies in many fields due to their effects on Turkey's urban, social, economic and political aspects. Today, architectural structures belonging to railways in Turkey consist of 4 main groups: Railheads (important train stations where the railway ends), Train Stations (at the middle of the railway) Suburban Stations and High-Speed Train Stations. This research examines the architectural, aesthetic and material features of train stations in Turkey, their changes and their effects on the urban texture and morphology in the past and today, how they were constructed, used and repaired structurally and materially, how they were re-used for different purposes. Three case studies of historical train stations as İstanbul, Ankara and Konya Train Stations, which are located on the high-speed railway network of Turkey, were analysed in architectural and structural aspects and at urban, regional and national scales, with considering their relations with newly built high-speed train stations.

Keywords: Historic train stations; High-Speed Train Station; Conservation of cultural heritage; Modern Turkish Architecture; Ankara train station; İstanbul train station, Konya train station.

1. Introduction

Railways, which have been instrumental in important developments in the world and in Türkiye, have led to the formation of new structures and urban areas, and have brought with them many effects reflected in urban architecture. In every settlement area where railway buildings and rails pass, effects such as acceleration of transportation and raw material supply, improvement of infrastructure, revival of production and employment, increase in cultural interactions, urbanization and migration have been observed (Başar & Erdoğan, 2009, 29-30).

The station buildings constructed with the construction of railways, although they were mostly located outside the city settlement during the period they were built, created a force of attraction over time and paved the way for physical, social, cultural and economic transformation in their surroundings. Railway buildings reflected the characteristics of both the city they were located in and the period, and at the same time became a symbol of the change they created in the city, the development they provided and the new areas they created. Station buildings may reflect the culture of the region they were built in or the culture of the country that built them, and may also include the interpretation of the old architectural language with today's conditions (Başar & Erdoğan, 2009, 30-32). With the change and development of train technology, new technologies and architectures have also begun to be used in addition to old systems and structures. For these reasons, the architecture of railway structures, their interaction with the city and the relationship of old structures with the new are multifaceted and worth researching.

The fact that train station structures were built by foreign architects in those periods led to the emergence of structures inspired by different geographies. The station buildings built by European states served as an educational

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tool for local architects, leading to the more frequent use of new trends and architectural technologies in the country (Başar & Erdoğan, 2009, 32).

Then, the national architectural movement, which started in Anatolia close to the declaration of the Republic of Türkiye, led to the formation of national architectural structures in cities such as Ankara, Eskişehir, Konya, Adana and Kayseri. Before World War II, the New German Nationalist Movement that emerged in Germany also affected Turkish architecture, and traditional motifs in architecture faded away. During this period, rational uses of reinforced concrete and steel began to prevail on an international scale. This situation is especially seen in Ankara Train Station and its surroundings and in Eskişehir's new train station building. Especially after 1931, local architects were supported to produce architectural works using local materials (Tankut, 1994, 23, as cited in Yakın, 2021, 42). From the 1960s onwards, architectural design concerns and aesthetic efforts began to disappear in train stations built in Türkiye (Yılmazyiğit, 1991, as cited in Başar & Erdoğan, 2009, 32). After these dates, the increase in investments in road transportation caused the railways to become secondary. The railway structures built by the state began to become ordinary buildings with no concern for style.

From past to present, train stations have held an important place in the memory of the city dwellers as public structures that form the identity of the city, the prestige and symbolic structure of the city (Özkaynak & Korkmaz, 2019, 216). The place of train stations in the architectural memory of the society has been used as an ideological, cultural, economic tool and/or symbol (Yakın, 2021, 38-39).

2. Materials and Methods

2.1. Train Stations in Architectural and Urban Scales and Relationships between Old and New Structures

Train station structures, due to both their functions and architectural characteristics, create a focal point for the surrounding area. They create a gravitational effect similar to that of a square or a bazaar that brings people together in the settlement they are located in (Akdemir & Keskin, 1993, as cited in Başar & Erdoğan, 2009, 39). Railways, on the other hand, enabled rapid product transportation and passenger travel in the areas where they were located, accelerated trade and production in the areas where the railways passed, revived cultural interaction with the outside world, and increased population and investments through migration (Ayvaz & Halaç, 2023, 65). In short, an important determining factor of the city identity (Uslu et al, 2025, 430), railway structures act like a magnet in the urban fabric of the city they are located in, becoming

Although there are many station structures on the railway line, the most important ones are the main stations, which serve as an ending and a beginning, are generally located in the city center or close to the center, and become an urban image and landmark for the city. These structures were generally designed by famous architects, and since the political, economic, cultural and social structure of the period was greatly influential in their design, they have become important historical documents. Train stations have served as a gateway to the outside world for city dwellers, and have held an important place in the memories of visitors as the first structure they encountered in the city (Yıldız, 2013, 52).

Railway lines and structures are entering a transformation process, where the effects of the 21st century in transportation are intensified, systems are modernized, and passenger and freight capacity is increasing. In particular, new technology high-speed train systems and the construction of new high-speed train stations are replacing existing railway structures (Sedes & Çıkrıkçı, 2022, 1554). Due to new technologies, historical train stations are in danger of losing their function that has a place in the memory of the society or becoming the focus of other profit-oriented investments.The High Speed Train Lines under construction are located very close to the historical station buildings in many cities such as Ankara, İstanbul, Konya, Eskişehir and Sivas. However, these new structures are far from complementing the existing station buildings, but they are a dominant structure that is integrated into the urban fabric. In fact, these new High Speed Train Stations located in the city center stand out by being significantly different from the existing settlement texture in terms of volume, ratio, proportion, facade and material (Sedes & Çıkrıkçı, 2022, 1554), causing the historical railway axes to become secondary and the station buildings to become dysfunctional. This situation creates physical, social and economic transformative and transformative effects on the urban fabric that has been shaped around the historical station for many years.

2.2. Selected Examples of Train Stations of Three Cities of Turkey: İstanbul, Ankara, Konya

In this article, the main station buildings (railhead stuctures) of historical railways and the main high-speed train lines from three metropolitan cities in Türkiye (İstanbul, Ankara, Konya) were examined comparatively. In the selection of these cities, the criteria has been determined as having both a historical station structure that has become the image of the city and high-speed train lines associated with it. The relationship between these historical and new station structures and how the stations and stations built with new technologies affect the urban texture that developed around the old station were examined.

2.4.1. İstanbul Train Stations

From 1872 onwards, the opportunities provided by the railway caused the trade volume to increase gradually in Haydarpaşa, and the Ottoman Empire gave the railway and port constructions to German companies due to the political circumstances. The first Haydarpaşa Train Station was a wooden 2-storey building, which existed between 1872 and 1939. This structure served a single-track railway between Haydarpaşa and Pendik (passing through Kızıltoprak, Feneryolu, Göztepe, Bostancı, Maltepe and Kartal stations). Haydarpaşa Port, designed and built by the Philipp Hollzmann company, was opened in 1903, which increased passenger traffic, and therefore a comprehensive train station structure that could serve together with the port was needed (Kösebay Erkan, 2013, 103-104). The station to be built would be the starting point of major projects connecting Istanbul to Baghdad and connecting Europe to the Hejaz and the Persian Gulf (Başar & Erdoğan, 2009, 33).

Todays Haydarpaşa Train Station in Kadıköy, İstanbul, has been built in 1908 with the Concession given by the Ottoman Empire to the Germans, designed by Hellmuth Cuno and Otto Ritter. The building has become an urban, architectural, aesthetic and social image of the city and a landmark with its striking appearance on the shores of the Bosphorus since the beginning of the 20th century. Haydarpaşa was designed at the request of Abdülhamit II, reflecting the magnificence of the period and containing a variety of forms. It has an eclectic style that bears the symbols of the Ottoman Empire, Middle Europe Baroque, German Renaissance, with its empire style decorations (Kösebay Erkan, 2013, 108), which are considered the second phase of neoclassicism (Fersan, 1991, Koçer, 1995, Soğancı 2001, as cited in Başar & Erdoğan, 2009, 33). The structure is a masonry system supported by steel beams in places and its foundations resting on wooden piles. The north door of the building served arriving passengers, while the south door served departing passengers. In first floor plan, there are sections such as offices, waiting rooms, conference rooms, glass-fronted offices above the passenger lounge. There is a manager's office in the north tower, and a general manager's office in the south tower. There are also offices in the short arm, and an inspector's room, telephone and telegraph rooms in the long arm. The most important feature of Haydarpaşa today on an environmental scale is that it is a symbolic structure that has been used by the masses for over a century.

Yonca Kösebay Erkan has worked on the interaction of Istanbul's railway heritage with the Marmaray project, which connects the Asia and Europe continents with an undersea railway tunnel (Kösebay Erkan, 2012a, 2012b). After the Marmaray Project began to take shape in 2004, the presentation of Haydarpaşa Train Station to urban competition brought about discussions. The Marmaray Project connect the Anatolian side of Istanbul to the European side with a tunnel passing under the Bosphorus, which has removed Haydarpaşa from being a starting or ending point in urban transportation. This situation led to legal changes that allowed the 1 million square meter area, which includes the Haydarpaşa Train Station and its surrounding area, to be reused for functions such as hotels, etc., instead of serving the original function of the building. Although TCDD officials applied to the Constitutional Court to cancel the decision to declare Haydarpaşa and its surroundings an urban protected area, the decision has not changed. The 1/5000 scale conservation zoning plan prepared for Haydarpaşa and its surroundings in 2009 was rejected as unconstitutional, and the new zoning plan study was approved by the Istanbul Metropolitan Municipality Council in 2011. The Conservation Development Plan prepared for the Haydarpaşa area in 2012 proposes a multifunctional, mixed use in the area and includes the use of the Haydarpaşa Train Station building for accommodation purposes (Kösebay Erkan, 2013, 99-101).Finally, although the Ministry of Transport of the Republic of Turkey announced that the building could not be a hotel, the function to be given was left unclear.

With the decision to connect the Rumelia railways, the most important railway of the Ottoman Empire opening to Europe, to Sirkeci, two small-scale two-storey and two four-storey station buildings, which do not exist today, were built on the seashore in 1872. However, the construction of the main station building (Sirkeci Train Station) began in 1888 upon the order of Abdulhamid II (Ayvaz and Halaç, 2023, 70). As the beginning of the Rumelia Railway Line, the structure serves as a gateway to Europe and foreign trade (Ayvaz & Halaç, 2023, 62). After the construction of Sirkeci Train Station was completed, it was called "The Gate of the East" by the Western states and "The Gate of the West" by the Ottomans (Durmaz Aktaş, 2019, 6, as cited in Ayvaz & Halaç, 2023, 65). Designed by German architect August Jasmund, who wanted to reflect Middle and Far Eastern influences, Sirkeci Train Station was put into service in 1890 as the starting point of the Istanbul-Sirkeci-Pythion railway. The building is Jahmund's only work in this style, and it influenced the styles of stations that would later be built in Central Europe (Büyükdemir 1999, as cited in Başar & Erdoğan, 2009, 34). There are eight railway structures in the Sirkeci Train Station Area. The first structure, built in 1972, is currently used as the Old Chieftainship Building. The structure of the State Railways Directorate of the Republic of Turkey was destroyed by fire, and the Section Chief, Locomotive Maintenance Workshop, Wagon Chief Service and warehouse structures remain idle and are not used due to the Halkalı station put into service (Ayvaz & Halaç, 2023, 73-74).

Although the Sirkeci Train Station area was declared a cultural area in 1995, the project aiming at a transformation focused on culture and arts has not yet been determined in its final lines (Ayvaz & Halaç, 2023, 74). The Istanbul Railway Museum was opened in Sirkeci Station on September 23, 2005. With the commencement of the Marmaray project on October 29, 2013, Sirkeci Station was closed. On March 12, 2019, it was decided that the railway line between Sirkeci and Kazlıçeşme would be used as both a railway and a recreational area, and trains returned to Sirkeci Station on February 26, 2024. between the State Railways of the Republic of Turkey and the General Directorate of Cultural Heritage and Museums in 2024, Today, Sirkeci Station is on the industrial heritage routes determined by ERIH (Geyyas Gören & Manisa, 2021, 882).

With the protocol signed between the General Directorate of TCDD Operations and the General Directorate of Cultural Heritage and Museums in 2024, the Haydarpaşa and Sirkeci Station buildings and areas outside the railway function were transferred to the Ministry of Culture and Tourism for 29 years to be used for "culture and tourism" purposes ("Haydarpaşa ve Sirkeci garları 29 yıllığına devredildi", 2024). The threat of losing the original functions of Istanbul's most important train stations has been met with public reaction.

It is known that there is no symbolic railway structure in the area where the Söğütlüçeşme High Speed Train Station is located. The Söğütlüçeşme Main Station Project is planned to be built in this area ("Söğütlüçeşme Anagar Projesi", n.d.)

Fig 1. Haydarpaşa Train Station (Retrieved from http://www.kadikoy.gov.tr/haydarpasa-gari-ilcemiz#gallery-1)

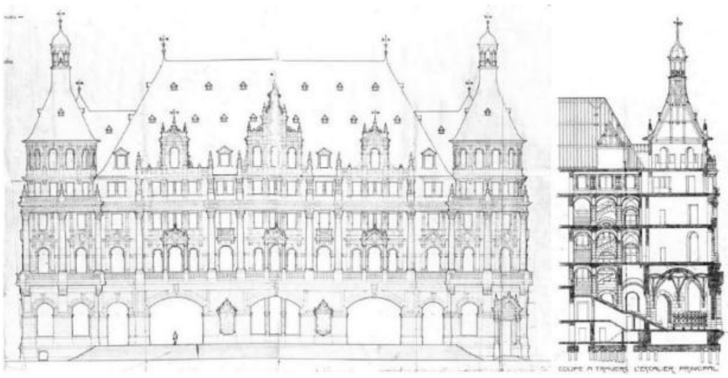

Fig 2. Main Façade and South Tower Detail of Haydarpaşa Train Station (Istanbul Railway Museum Archive, as cited in Kösebay Erkan, 2013, 108-109).

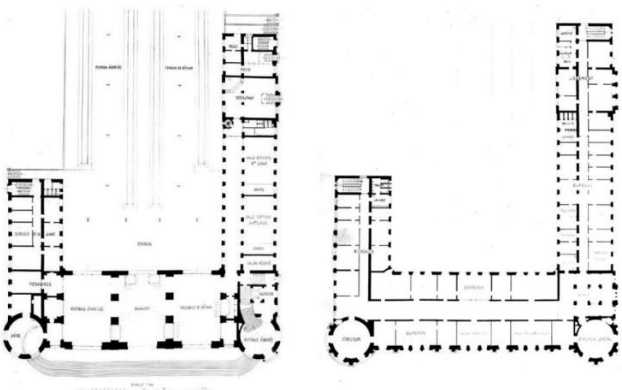

Fig 3 . Ground and First Floor Plan drawings of Haydarpaşa Train Station (Franfurt Institut für Stadtgeschichte Archive, as cited in Kösebay Erkan, 2013, 106).

Fig 4. Sirkeci Train Station (Retrieved from https://esenler.bel.tr/esgev/takvim/sirkeci-tren-gari-muzesi/)

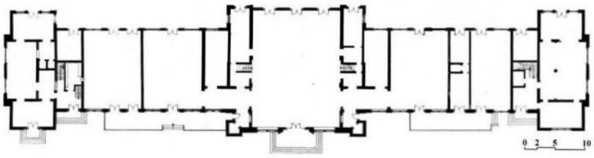

Fig 5. Ground Floor Plan of Sirkeci Train Station
(Sözen, 1973, as cited in Başar & Erdoğan, 2009, 34).

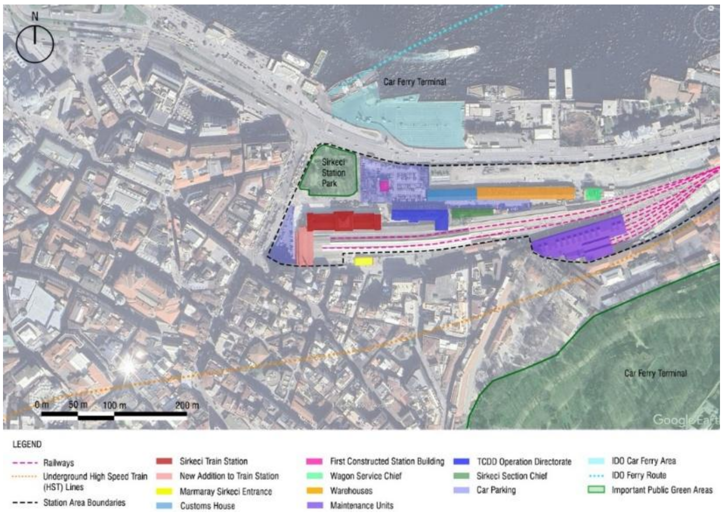

Fig 6. Building Functions Around Sirkeci Station Complex (Google Earth, 2025, Ayvaz & Hanım Halaç, 2023, 72; https://tr.railturkey.org/wp-content/uploads/2021/09/sirkeci-kazlicesme-rayli-sistem-guzergahi.png?w=800 , Reproduced by authors.)

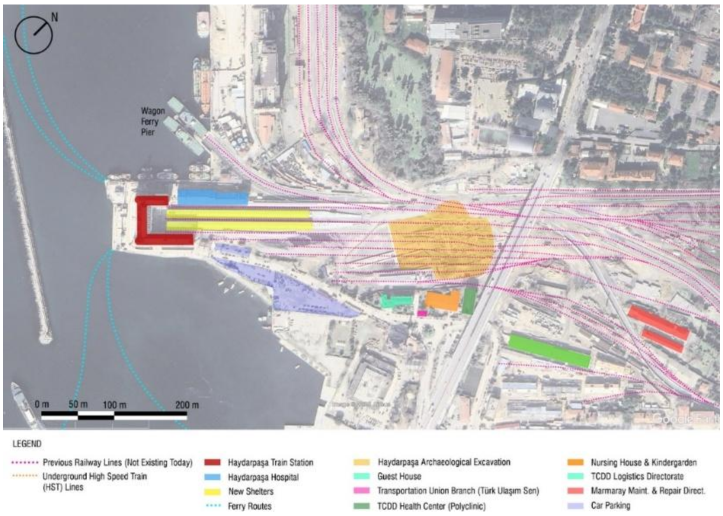

Fig 7. Building Functions Around Haydarpaşa Station Complex (Google Earth, 2025, Reproduced by authors.)

2.4.2. Ankara Train Stations

The old Ankara Train Station, which no longer exists, was built when the first locomotive arrived in Ankara in 1892. This structure has the same plan and facade layout as the first train station of Eskişehir, and very similar to the train station of Konya (Başar & Erdoğan, 2009, 35). Later, Ankara Gazi Station, which is designed by Ahmet Burhanettin Tamcı in 1926, the project became a symbol for the capital Ankara as one of the first station buildings of the National Architecture Period (Başar & Erdoğan, 2009, 36). Then, Ankara Train Station Building of today, described as the entrance gate of Ankara and one of the important structures of the Republic Period, has been constructed in 1937 and became a symbolic structure due to its architectural features. It was designed by architect Şekip Akalın, with the views of Professor Blum from Germany about the size and location of the station, and put into service in 1937. The role of the station structure is to reflect the power of the young republic and to create squares and spaces for the modern city dweller to pass through. Since the station is the first gate that those coming to the city pass through, it was aimed to meet the Youth Park with its landscaping and pools, in contrast to the arid and barren climate created by the geography. (Yakın, 2021, 42-43).

The building has a symmetrical volume and has 4 floors starting from the basement. There are circular staircase blocks on both sides of the entrance tower. The ceiling of the waiting hall is made of opaque laminated glass on a metal construction and allows daylight in. While the ground floor entrance hall contains buffets, ticket offices, luggage storage, staff offices, a barber and a lounge of honour, the upper floor of the side areas connected to the waiting room serve as lodgings (Uslu et al, 2025, 431). The reinforced concrete structure is covered with the characteristic pink Ankara Stone.

The important buildings around the Station Building, such as TR State Railways General Directorate Building, Direction Building, Ankara Hotel, 2nd Region Building, Train Maintenance House, Station Casino, lodging and guest houses, form a complex (Uslu et al, 2025, 432). Also, this structures are in a close physical relation with the newly constructed Ankara HST station. In 2019, a portion of the Ankara station buildings and the southeastern half of the Ankara station area were transferred to the use of a private university (Altın, 2025, 370). Located close to the station and built in 1927, Maintenance Units (*Cer Atölyeleri*) has been used as a modern arts center and art gallery with a since 2010, Wwith adaptive reuse found to be architecturally successful (Uysal et al., 2019, 76, Geyyas Gören & Manisa, 2021, 890).

Ankara HST Station was built on October 29, 2016, on the land next to Ankara Train Station, as a commercial complex consisting of the main high-speed train station and social areas such as a shopping mall, cinema, hotel, meeting halls, etc. Ankara HST Station was built as a total of 8 floors, approximately 400 meters long and 220,000 square meters of closed area. Ankara HST Station, unlike the old train stations, was built with the "build-operate-transfer" model. As a result, it has moved away from being a purely service-oriented public structure and has become a partially commercial investment. The structure was designed not only as a transportation venue but also as an urban center, even similar to a shopping mall. (Yakın, 2021, 49-50). It is seen that the station buildings in Ankara have transformed from a single small-scale building to a campus consisting of many buildings, and following the high-speed train technology, they have been designed as a large mass where all functions are gathered. In fact, it has been discussed architecturally that the new station, so close to the old station but so different in terms of scale, almost makes the old station structure invisible.

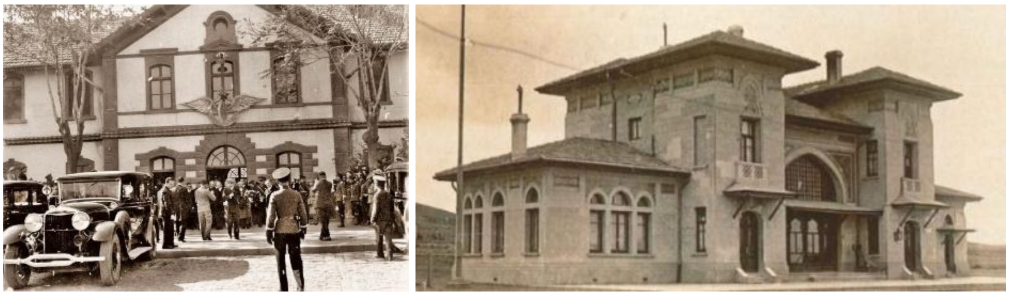

Fig 8. Old Ankara Train Station and Gazi Station
(Retrieved from http://www.eskiturkiye.net/2577/eski-ankara-tren-istasyonu-1930-lar/ and https://kulturenvanteri.com/yer/gazi-tren-istasyonu/)

Fig 9. Ankara Train Station in 2024 (Photographed by the authors.)

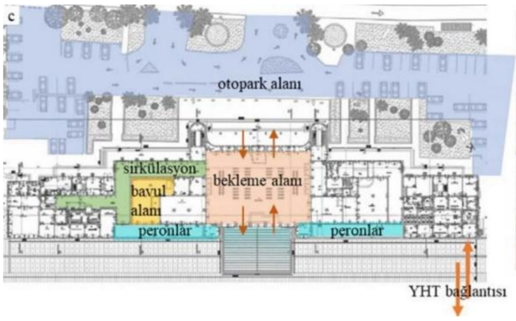

Fig 10. Ground Floor Plan of Ankara Train Station (Uslu et al., 2025, 431)

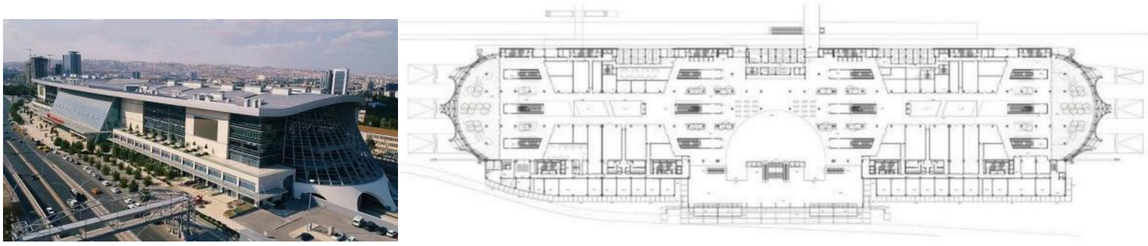

Fig 11. Ankara HST Train Station (Yakın, 2021, 49 & https://raillynews.com/2018/10/ankara-yht-gari-became-the-new-life-center-of-the-capital/)

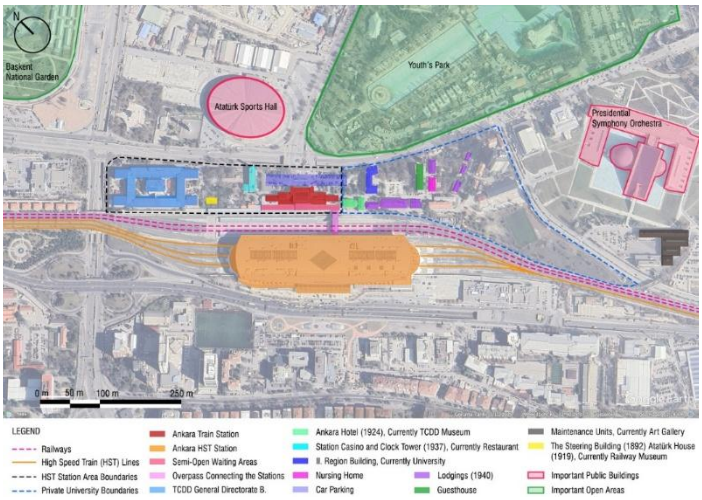

Fig 12. Building Functions Around Ankara Station Complex (Google Earth, 2025, Uslu et al., 2025, 432, Reproduced by authors.)

2.4.3. Konya Train Stations

First Konya Train Station was built in 1896 as the end point of the Eskişehir-Afyonkarahisar-Konya railway, which was built by the Chemins de Fer Ottomans d'Anatolie / Ottoman Anatolian Railways (CFOA) Company between 1894 and 1896 with an eclectic style (özkaynak & Korkmaz, 2019, 220). Konya station buildings were built as a complex along with other complementary structures, on a 160 x 22 m land (Yavuz Pakih & Sarıman Özen, 2022, 885).

For the main station building, stone, brick and wood materials were used in the masonry structure and the walls were plastered. Windows and doors on the facades are emphasized with stone arches. The arc-shaped structure located northwest of the Main Station building is a maintenance workshop structure consisting of 13 sections and houses a circular platform used to turn the locomotives in the direction they will enter. A section of this structure was demolished due to the road changes planned around it (Uysal et al., 2019, 80). After the 2014-2015 restorations, the 14 lodging structures were rented to the municipality and private institutions and started to be used for other purposes (Yavuz Pakih & Sarıman Özen, 2022, 886). Today, it is observed that the Konya Train Station Complex cannot keep up with changing conditions, developing technology and urbanization, and reuse proposals are being developed for the structures (Uysal et al., 2019; Yavuz Pakih & Sarıman Özen, 2022).

As addition to historical train station, a new station building is constructed in 1956 (Özkaynak & Korkmaz, 2019, 216). While the scale of the building can be considered compatible with the old building, its incompatibility in terms of architectural language has been subject to criticism. Konya Train Station has also started to be used as a stop for the High Speed Train. However, due to the expansion works to be carried out on the Meram Yeniyol Bridge, it will not be able to provide service for three months as of March 10, 2025 (Elmas, 2025).

Fig 13. Konya Historical Train Station
(Selman Bayrakçı, Retrieved from http://turkiyeturizmansiklopedisi.com/konya-tren-gari and https://www.dogrulukpayi.com/dogruluk-kontrolu/konya-daki-tarihi-tren-gari-yikilip-yerine-yenisi-mi-yapildi)

Fig 14. Konya New Train Station constructed in 1956 (Retrieved from https://www.ilgihaber.com/konya/konya_meram_yuksek_hizli_tren_gari_kapatildi_yht_yolcularini_neler_bekliyor-162535h#google_vignette & https://www.yenikonya.com.tr/konya /konya_meram_yht_gari_kapatildi_ konya_meram_yht_gari_ne_zaman_acilacak_iste_alternatif_ulasim_secenekleri-1946145)

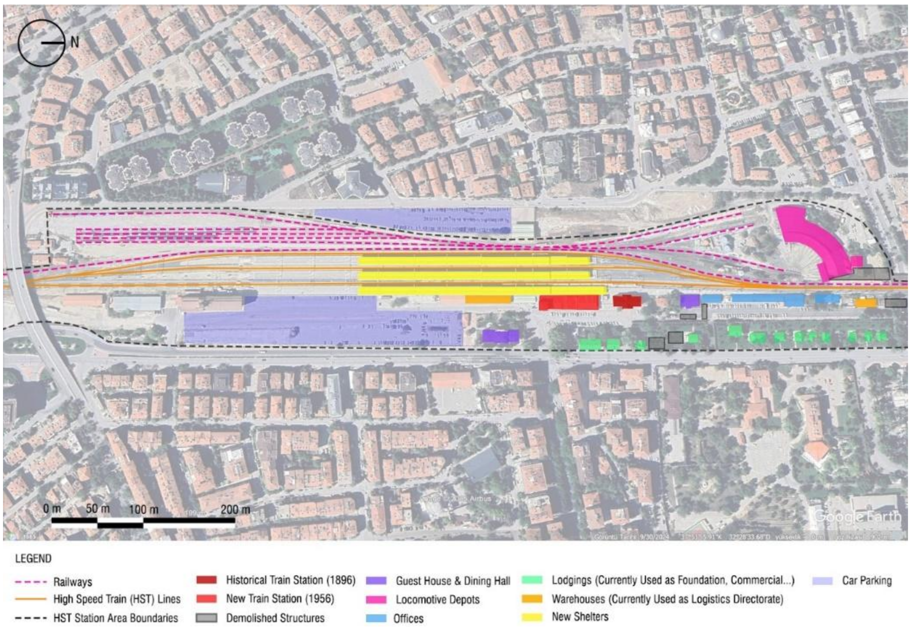

Fig 15. Building Functions Around Historical Konya Train Station
(Google Earth, 2025, Yavuz Pakih & Sarıman Özen, 2022, 885, Reproduced by authors.)

With the arrival of high-speed train technology in Konya in 2011, the Selçuklu Station Building, whose project was prepared in 2013, put into service on October 2, 2020. Currently, there are two high-speed train stations in Konya city. Selçuklu YHT Station is the first stop for high speed trains coming to Konya city, close to commercial areas and the tram stop, constructed in October 2021, which is 4.5 km far away from the city center. The second Konya HST Station, located on the site of the old Konya Train Station, consists of only a superstructure. On the other hand, Selçuklu HST Station onsists of a vertical big rectangular mass on a horizontal road route and platform structures adjacent to it parallel to the road. It is considerably larger and more dominant than the surrounding buildings in terms of scale and silhouette.

3. Results and Discussions

Effect of high-speed train stations on existing urban texture around train stations in selected examples are examined in this section with comparison of aerial photograos from different years.

3.1 İstanbul

When the existing port activities in Sirkeci and Haydarpaşa were supported by the railway, the trade volume of the area reached its highest level and it became an important logistics and commercial center in freight transportation. With Haydarpaşa and Sirkeci Train Station Areas, the city has experienced developments in social and economic areas, and with increasing industrialization, production facilities, shipyards, warehouses, and industrial enterprises have been put into service in the port and coastal areas close to Haydarpaşa and Sirkeci (Ayvaz & Halaç, 2023, 68, 71).

In addition to the construction of the Sirkeci Train Station, the construction of warehouses and docks in the area changed the character of the area and allowed the city to take on a new identity (Kuban, 2010, 99, as cited in Ayvaz & Halaç, 2023, 72). Around Sirkeci Train Station, there are important city places such as Topkapı Palace, Gülhane Park, Sultanahmet Mosque, Hagia Sophia Mosque, Mısır Bazaar, Galata and Golden Horn bridges.

The opening of the Marmaray Tunnel (for railways) in 2013 and Avrasya Tunnel (for automobiles) in 2016, which connect the Asian continent to Europe and passes under the Bosphorus, and the construction of the High Speed Train 2014 have caused Istanbul to undergo many changes on an urban scale. The facilitation of intercontinental and intercity railway transportation for Istanbul has paved the way for new investments. Two city parks, one of which is the largest in the world, were built by filling the sea in Maltepe and Yenikapı in Istanbul in 2014, increasing the surface area of İstanbul by approximately 2 square kilometers. In the Kadıköy-Fikirtepe neighborhood, which is very close to Söğütlüçeşme HST station, a comprehensive urban transformation project and the construction of multi-storey residential buildings have greatly affected the urban fabric. The Fikirtepe urban transformation area is an example of the changing and transformative effect of newly constructed railways on the city.

3.2. Ankara

Ankara was chosen to lead the country entering a new era in the Republican Period, and planned development was implemented as a method of achieving this (Tankurt, 1994, 23, as cited in Yakın, 2021, 42). In 1925, with the efforts to modernize and strengthen production, Atatürk Forest Farm (AFF) was established by Mustafa Kemal Atatürk on a 50,000,000 m² land, in order to realize pioneering developments in production. Ankara Gazi Station is also located within the borders of Atatürk Forest Farm.

Throughout time, the capital Ankara has become a much more traveled place compared to the past, which has led to the inadequacy of Gazi Station and the need for a new train station. The new train station is located between Anıtkabir and Gençlik Park, at the intersection of Talatpaşa Boulevard, Cumhuriyet Avenue and Hipodrom Avenue, which are important transportation axes of Ankara. Then, with the arrival of high-speed train technology in Ankara, the High Speed Train Station, which is closely related to Ankara Train Station, was built, and this led to an increase in investments and construction around the station.

For Ankara, it is seen that the Atatürk Forest Farm, which started to disintegrate in Ankara in 2006, is gradually losing its green land due to new constructions. Reasons such as the failure to protect the Atatürk Forest Farm as a whole and the construction taking place on lands allocated for agriculture have caused the farm to disintegrate. In this case, it can be investigated whether the construction investments that started after the Ankara High Speed Train project have an effect on this disintegration.

3.3. Konya

While the old train structures of Konya are located as a campus in the city center, Selçuklu HST station is located next to the industrial center, 4.5 km away from the city center, as a large mass that includes all functions. The nearest residential area is 300 meters away. The structure is designed to serve as a bridge connecting the two sides of the city by crossing over the railway line. With the selection of the location of the HST station, it was aimed to transform the surrounding small industrial center into a new center with residential, social and commercial structures by joining the urban transformation areas. It was aimed for the HST station to be integrated with transportation axes such as tram, bus, suburban train, light rail system, etc. and to give the city a new identity (Özkaynak & Korkmaz, 2019, 222). In fact, it can be observed from aerial photographs that there are urban transformation areas around the train stations in Konya, and that the urban fabric has been completely renewed in a fairly large area.

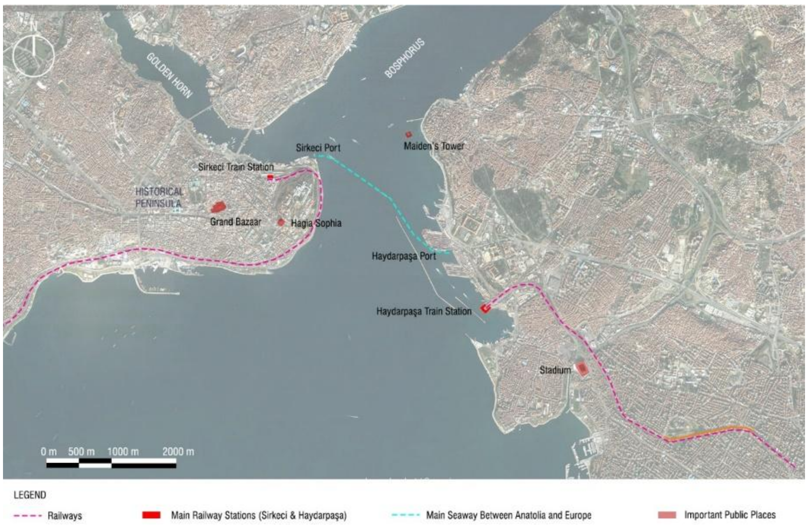

Fig 16. İstanbul Aerial Photograps in 2007, before the construction of HST and Marmaray Tunnel. (Google Earth, 2025, Reproduced by authors.)

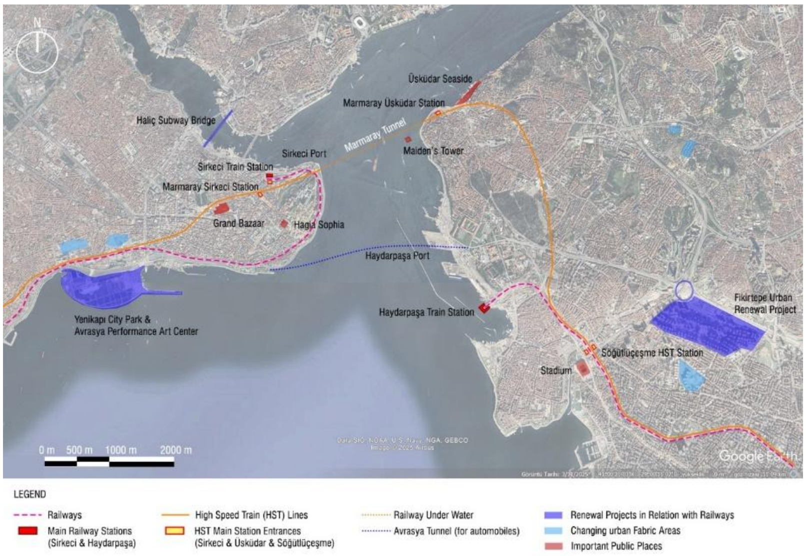

Fig 17. İstanbul Aerial Photograps in 2025. (Google Earth, 2025, Reproduced by authors.)

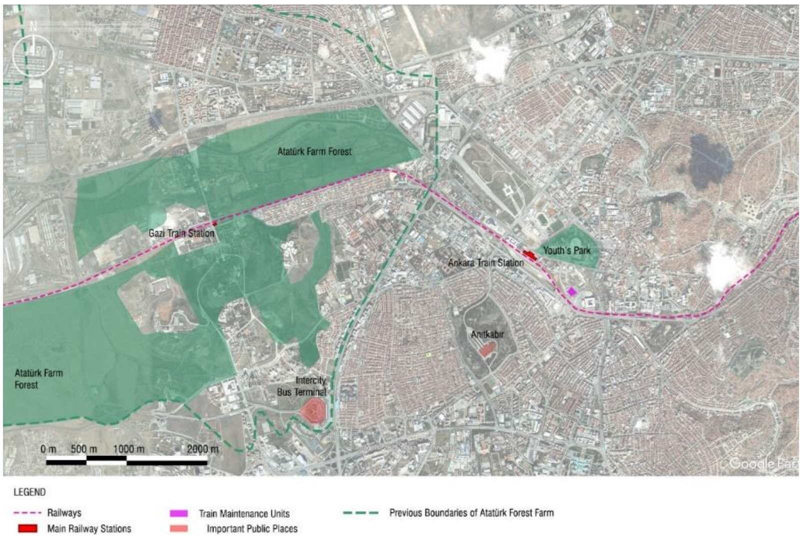

Fig 18. Ankara Aerial Photograps in 2007, before the construction of HST. (Google Earth, 2025, Reproduced by authors.)

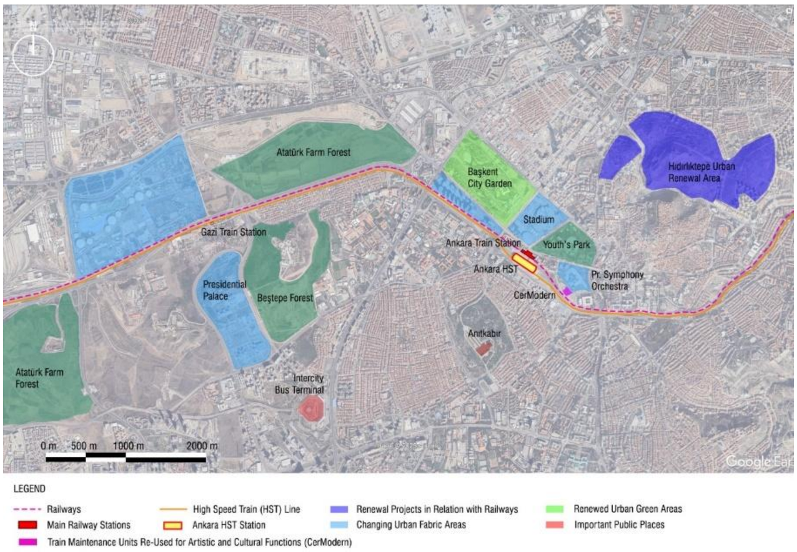

Fig 19. Ankara Aerial Photograps in 2025. (Google Earth, 2025, Reproduced by authors.)

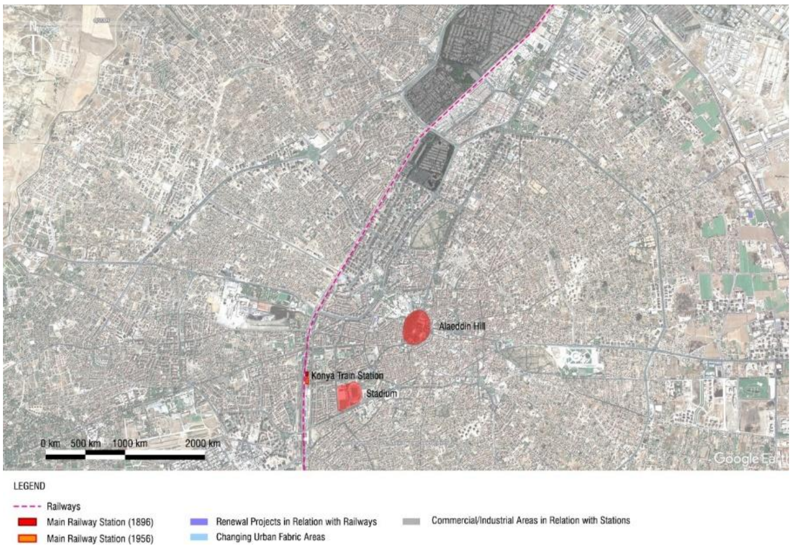

Fig 20. Konya Aerial Photograps in 2007, before the construction of HST. (Google Earth, 2025, Reproduced by authors.)

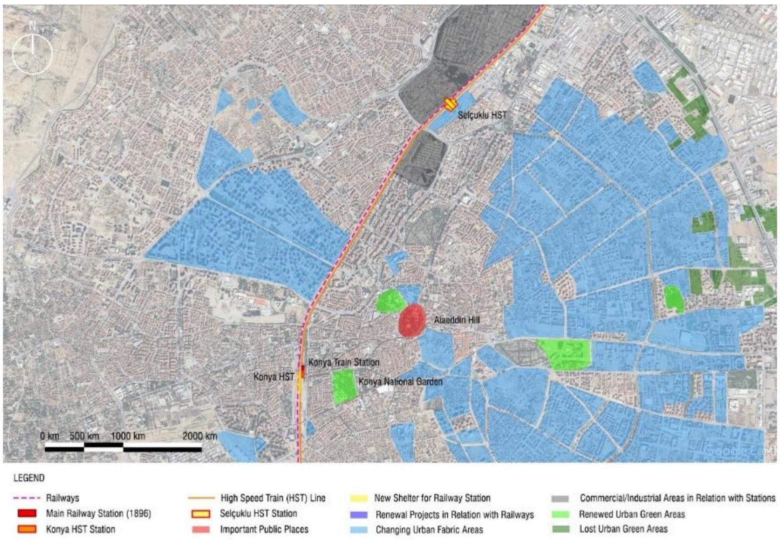

Fig 21. Konya Aerial Photograps in 2025. (Google Earth, 2025, Reproduced by authors.)

4. Conclusions

The crumbling Ottoman Empire made efforts to keep up with global developments, to make cities livable by granting privileges to foreigners, and to build railways and train stations. The advancement of railway technology and the constant change and transformation of station structures in terms of architecture were shaped by factors such as political policies, the socio-cultural situation of the period, and the economic structure of the state. Railways are versatile connecting elements that are not limited to space, in terms of establishing connections between other cities, ensuring the flow of goods and people, and ensuring integration between regions (Sedes & Çıkrıkçı, 2022, 1552). Station buildings, generally positioned close to the city but not restricting city development, are designed as a living campus within themselves (Uysal et al., 2019, 68).

The High Speed Train technology, which was put into service in Japan in 1964, started to be used in Türkiye with the commissioning of the Ankara-Eskişehir HST line on March 13, 2009. HST, which is preferred by passengers more because of the time and comfort it saves, has caused traditional train systems to become secondary and even some train station structures to become idle. In some cases, since it is not possible to transfer old train structures to future generations and maintain their current functions (Ayvaz & Halaç, 2023, 65), adaptable reuse proposals have been made for the structures.

On the other hand, high-speed train stations under construction may be dominant and contemporary structures that are integrated into the urban fabric, far from being complementary to historical station structures. These structures, which differ in volume, proportion and facade, may have negative effects on historical stations (Sedes & Çıkrıkçı, 2022, 1554) and may also cause changing and transforming effects on the urban fabric. HST stations, which change the linear and multi-part campus/complex pattern of the railway structure, gather all the functions in a large mass, create a focus within the city and cause differentiation in the settlement texture. This situation distances them from integrating with the old station structures, on the contrary, makes it difficult to perceive the original stations. In addition, HST stations as macro projects at the urban scale can cause significant changes in the settlement texture, landmarks and focal points, silhouette and socio-economic structure in historical areas. They may also lead to the loss and loss of identity of old train stations (Markoç & Elyazıcıoğlu, 2014, s cited in Sedes & Çıkrıkçı, 2022, 1557).

Railway structures can be evaluated within the scope of architectural, historical, cultural and industrial heritage. However, preserving these structures, which have been damaged and relegated to the background over time, with sustainable strategies and transferring the values they contain to future generations requires close cooperation between institutions such as the Republic of Turkey State Railways, Cultural and Natural Heritage Protection Regional Boards and the Ministry of Culture and Tourism.

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The ecological survey of semi-open spaces in hot-dry climates to achieve a cultural and zero-energy housing model

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Abstract. Visual and thermal comfort for the inhabitants of residential spaces significantly depends on the weather conditions of the external environment, which are constantly changing, and these changes are visible due to the climate contrasts according to the culture of each region of the world. The research method is based on qualitative and quantitative, ENVI-met software is used for climate calculations, Python software, and igraph is used for fuzzy data. The dominant architectural forms and structures of these spaces in the studied hot and dry climate region are closely compatible with local resources, land, culture, and climate, and are related to the human need for a culture-oriented housing and the identity of hot and dry regions. Concept of sustainability and its special position is emphasized. The research findings can contribute to the critical rethinking of semi-open spaces and their intrinsic value in renovation projects as well as in contemporary residential architecture.

Keywords: Semi-open spaces; Housing anthropology; Cultural ecology; ENVI-Met; Python

1. Introduction

Occupant's comfort and energy consumption are critical issues within the field of structural plan and building innovation. The request for warm and visual consolation from inhabitants has been expanded impressively. The vitality utilization and CO_2 emanation as well as the capital taken a toll of building's operational vitality have been expanded. The utilize of passive plan techniques within the early stages of the plan may be a need for modelers and engineers to optimize the benefits from on-site renewable vitality assets such as sunshine. Be that as it may, optimizing inhabitant consolation by utilizing sunshine is challenging since there are two unmistakable spaces counting insides (interior) and the environment (exterior), which are association together. Moreover, optimizing visual and warm consolation is troublesome due to clashes between them. In specific, sun diurnal developments giving rise to diverse hourly sunshine circumstances that impact the indoor consolation conditions. Be that as it may, intrigue consider through building plan, light and human well-being seem lead to the discovery of ideal arrangements with respect to all previously mentioned criteria.

Semi-open spaces (i.e., open spaces with roofs) have constituted an essential component of innate private structural plans over the past centuries. These inactive plan components reflect the genuine parameters of the communities and societies of the locale, as they react to the gentle climate conditions, way of life designs, and mindset of the nearby individuals (Sadanand, 2020). Rudofsky, within the book Design Without Designers, a presentation to non- pedigree design, emphasizes the natural and social qualities of conventional semi-open spaces (Rudofsky, 1964). The plan of these spaces was based on a profound understanding of nature, climate, and accessible assets, as well as the characteristics and values of the prevailing way of life of the inhabitants. Agreeing with Foruzanmehr (2015), conventional semi-open spaces may be more reasonable for a wide run of social and individual exercises compared to open spaces (Foruzanmehr, 2015).

Artificial intelligence today is undoubtedly an interactive and disruptive technology, with countless applications and more prospects for every industry and background, from healthcare to agriculture, engineering to finance, sports transport, and more (Cugurullo, 2020). In addition, artificial intelligence is one of the main drivers of the world's smart city movement (Singh et al., 2020).

The research presented here aims to fill this inquire about crevice with an orderly survey and basic and all-encompassing survey of diverse shapes of semi-open and semi-open spaces in hot, and dry climates based on natural execution. Particularly, this investigate tries to relate their spatial, typological and basic characteristics (substantial values) with natural, utilitarian concerns (intangible values). It looks at conventional houses in several

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climates and topographies. This investigation is based on a comparative evaluation that can give experiences into how distinctive neighborhood conditions, for illustration, climate, geology, assets and way of life profiles, impacting parameters such as recurrence. Considering the danger of slow vanishing of these plan components, we expect that this think about will raise mindfulness for their preservation.

2. Research literature

2.1. Building form as a microclimate modifier

Regulatory function of façade benefits from modifying microclimate in ambient environment by controlling airflow, solar radiation across the facade body resulting in adjusting surfaces temperature of the building nearby the interior spaces. Courtyard building, as an old form of dwelling, pervasively applied in all times, climates and locations such as Iran, China and Middle East. Despite the socio-cultural aspects, courtyard building demonstrated extraordinary response to climate specifically in harsh condition. (Grobman, 2017). In addition, they concluded that a microclimate modifier can affect air movement, daylight, ventilation and living style resulting in improving thermal comfort in enclosed public area and surrounding spaces. Modifying microclimate is studied based on method, software, climate, microclimate modifier type, function, effective parameters and microclimate forces which are explained in the following. (Agency, 2020). Therefore, in the current research, we dealt with the hot and dry climate in three regions of the world, and in the first stage, a general understanding of this climate, and in the second stage, the investigation of traditional and responsive architecture in the hot and dry climate, and finally, the ecological investigation of open and semi-open spaces. Again, in a hot and dry climate, we will work towards zero energy housing (using Python and ENVI-met software).

2.2. Knowing the hot and dry climate

The planning should be compact, and under one roof to avoid a lot of movement, which can cause unnecessary thermal loading and discomfort to occupants. The orientation of the longer side facade should be North-South, as the solar radiations are less harsh than East or West. The sun moves from east to west; therefore, the sun's rays are at a maximum in this direction (Cauwels and Sornette, 2022).

The concept of planning in context with climate is seen in traditional times. Jaipur comes under a hot and dry climate, the Havelis were designed close to each other with narrow lanes, for an effective flow of wind as hot air when passed through narrow lanes cools the flow.

The shading is an essential part of hot and dry climates, unlike warm and humid climatic zones. Characteristics of Hot and Dry Region are as following:

- The temperature in these regions ranges from 27 and 49°C and 22 °C at night
- Humidity is moderate to low, with clear-skied most of the time
- The low humidity means less rainfall and therefore less vegetation in the region
- The wind flow is minimal but when there it's hot and dusty (Altomonte, 2020).

In recent residential projects, we have seen the need to bring the outdoors indoors, whether through green walls, Biophilic designs or interior courtyards, especially in countries with dry and hot climates. When it comes to countries with hot, dry climates, creating these outdoor-inspired interiors is about more than bringing in sunlight and fresh air, it's an architectural expression of a rich culture that spans generations. It goes beyond and inspires nations beyond their borders. In fact, how cultural and social norms affect the creation of traditional courtyard houses in hot and dry regions of the world and how to visualize their unique architectural features can achieve ecological sustainability in the field of building construction.

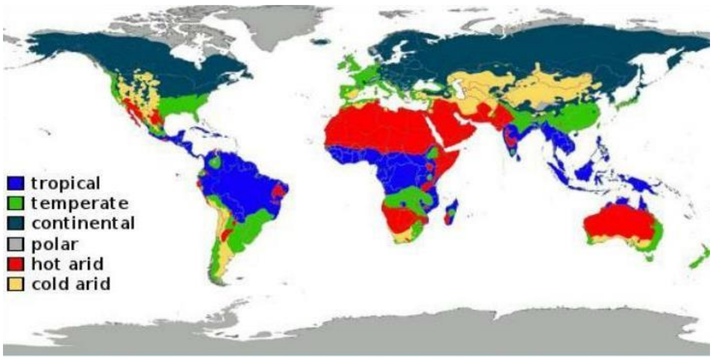


Fig. 1. Different types of weather in different parts of the world

2.3. Energy efficiency: Net zero energy building

In a net zero vitality building (NZEB), the sum of vitality is decreased by the legitimate plan of the envelope, cover and warm recuperation (winter), shade (summer), and normal ventilation. Agreeing with the definition of NZEB, the vitality required to function the building is delivered by renewable vitality sources in or close to the building. (Marszal, 2011). NZEB are characterized as the taking after standards including a) the utilization of renewable vitality sources on location, b) the yearly vitality utilization breaks even with to or less than the vitality generation from on-site sources, c) yearly capital fetched of operation rise to or less than the vitality lattice and d) diminishment of carbon emanations and reliance on fossil powers. In any case, Wang et al. (2009), the integration of detached plan methodologies and dynamic innovation within the shape of the dynamic veneer leads to an adjusted vitality prerequisite and a consistent reaction to diverse conditions. Inactive methodologies allude to cautious sun-based plans with the point of lessening warm pick-up, the requirement for manufactured cooling, warming, and visual glare (Kima, 2019) (Grynning, 2018) (See Fig. 2 and Table 1).

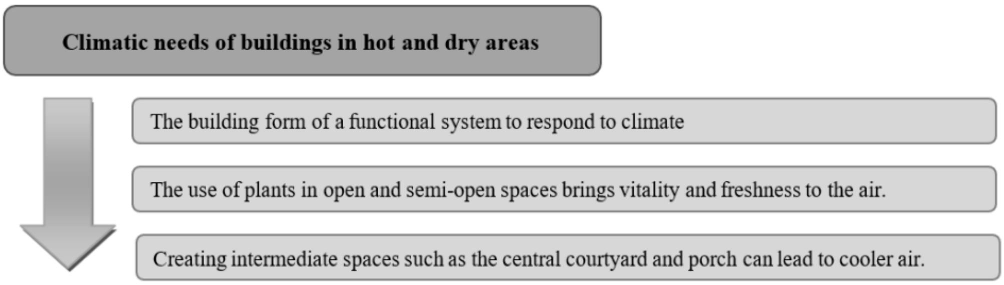
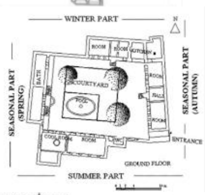
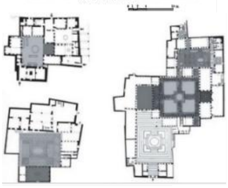
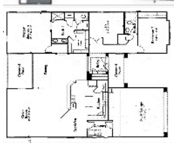
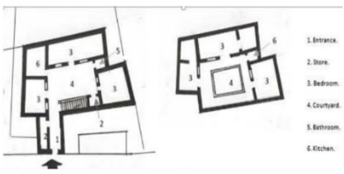
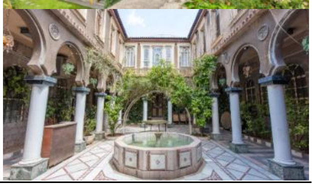


Fig. 2. Climatic needs of buildings in hot and dry areas

Table 1. Review of three case studies around the world based on native houses in hot and dry regions

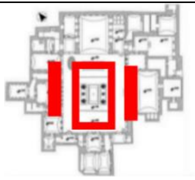
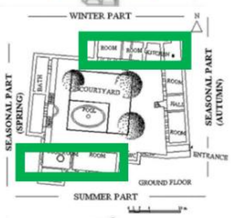
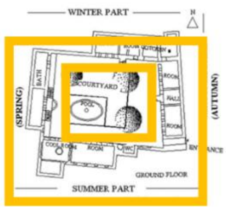
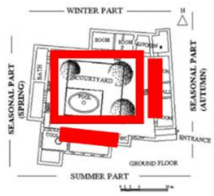
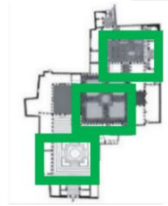
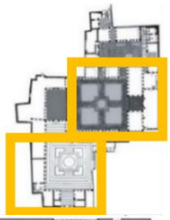
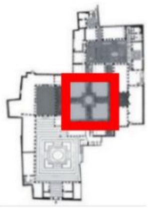
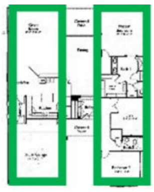
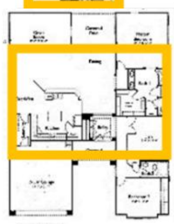
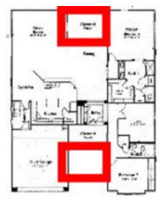
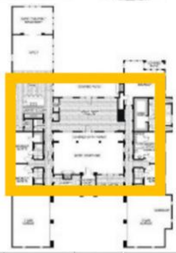
Area	Features	Plan	Open/semi-open spaces
Yazd - Iran	Central and semi-introverted courtyard Wide and high porches orientation (East-West)		
Diyarbakir-Turkiye	Use of thick walls for minimal heat transfer. The use of plants next to the external walls of the building for thermal insulation and air conditioning		
Sham-Syria	Introversion and central courtyard wide porches use of ponds and water ponds		
USA - Arizona	Using local materials to create sustainability. Using introverted spaces and central courtyard to create coolness and temperature balance		
Mexico	Using plants for shading. Use of balconies and windows with large openings		
Libya	The spaces of verandas from head-to-head inside the central courtyard. Culture and religion show introversion in this climate		

4. Discussion

4.1. Spatial syntax and culture

The syntax of space is a theory and method based on the abstract recognition of space, quantification of spatial components, and analysis of the relationship between comprehensive spatial systems and local construction. Based on this model, comparative research can separate the logic and rhythm of spatial distribution and combine spatial construction with the economic and social system. The aim is to reveal the causes, mechanisms, and development trends of the distribution of economic and social elements (Qin, 2023). In recent years, the syntax of space has been widely used to study the semantic relations of building culture due to its ability to study the relationships between spatial form, spatial structure, and human social behaviours (Zhang, 2021).

Table 2. Syntax of space based on climatic and native findings of housing in hot and dry regions

Area	Culture - religion	Climate	Sustainable Element
Yazd - Iran			
Diyarbakir-Turkiye			
Sham- Syria			
USA - Arizona			
Mexico			
Libya			

*: Culture-religion with this color indicates that spaces are separated into inner and outer based on cultural and religious intellectual principles, or the spaces have privacy. ; : The climate is shown with this color and thus the climate design refers to the introversion of the residential spaces around the central courtyard.; :The stable element is shown with this color and shows elements such as the central courtyard and the porch and balcony or the air cooling corridors that are common in all plans.

The syntax of the culture is related to privacy or permission to enter the house and is trusted. Therefore, the idioms of the realm of mahram bring intimacy, kinship and closeness. The meaning of culture in architectural buildings is to build a place in such a way that it has architectural symbols such as a porch and a central courtyard from both physical and semantic aspects (Gholshan, 2020). The style of space in the present research briefly refers to the formation of spaces in residential plans in hot and dry regions and how the culture of these regions has affected the arrangement of internal spaces.

5. Ecological investigation of open and semi-open spaces in hot and dry climates

Using ENVI-met software and the model presented based on outdoor thermal comfort indicators, the results obtained by Excel software will be presented and analysed in the form of graphical charts. The basic information that is needed for modelling is given in this step.

These data, according to the geographical location of the region, generally include the prevailing wind of the region throughout the year, whether at night or during the day, the westerly wind, according to the location of the region in latitude and the angle of sunlight in the lowest annual position and in the highest How many degrees is the annual position. Therefore, with the desired data, we will analyse separately the three cases mentioned in the table above. Modelling and analysis of the variables of orientation, height, sunlight and reflection, which are influential factors in thermal comfort, have been done in ENVI-met software.

6. Analysing the criteria with Python

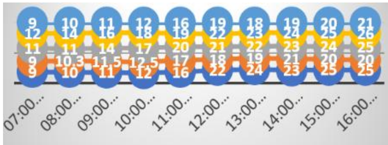
Performing numerical calculations using conventional Python methods and using the Pandas library can be converted into a quantitative method, and this main library for scientific calculations in Python helps speed up calculations and allows your system to work efficiently.

According to the above investigations and qualitative knowledge, it can be said that in a hot and dry climate, criteria such as temperature, humidity, air flow, if they are controlled by the climatic and ecological design approach, can be the optimal model in this climate for areas with this climate. The world was achieved.
Therefore, we will analyse the criteria based on coding and numbers in Python software to get a suitable answer in terms of measuring the criteria and the correctness of the assumptions.

Table 3. Distinctive features of traditional architecture of hot and dry regions of the world

Features	Description
The buildings are in the form of a central and semi-introverted courtyard	The climatic behavior of the central courtyard is such that with the vegetation and generally the water in it, it produces a microclimate in which the temperature is lower than the outside temperature and the air humidity is higher. In addition, the trees create shade and the breeze that is directed into the yard
The height of the rooms is high and the windows are long	The high height of the room is up to 4 meters, which causes the heat of the air to rise and the temperature to decrease in the lower height of the room, and finally, hot air ventilation through the windows under the ceiling
Wide and high porches	The presence of wide and shady porches and proper ventilation in the porch and the location around the central courtyard or on both sides of the building, which reduces the ambient temperature and comfort of the space
Orientation (east-west) of the building	Orienting the building in accordance with the wind direction, creating opposite openings to produce blinds, creating windy spaces (narrow and long alleys), using wind deflectors
Prevent heat and cold exchange	Using wood as the best type of material due to the slowness of heat transfer and the use of materials with high thermal capacity such as brick and straw that do not return heat to the interior space
Optimum use of building temperature in different seasons	Division of living spaces into two parts, summer and winter

Table 4. Based on the analysis made by ENVI-met software, the following results have been obtained

Area	Description	ENVI-met
Yazd – Iran	By examining the reflections of 40% and 94% for the surfaces around the courtyard, it was concluded that the reflection of 70% in the layers and side walls of the building benefit from the draft of solar energy.	
Diyarbakir-Türkiye	To receive solar energy for long hours and exchange air in the building, it is between 12:30 PM and 2:30 PM. This analysis is specific to the summer season.	
Sham-Syria	After examining the reflections of 62% and 97% for the surfaces around the courtyard, it was concluded that the reflection of 78% in the layers and side walls are less benefited from the solar energy draft	
Results	As a result, according to the above graphs, the effective indicators for receiving solar energy for long hours and air exchange in the building are between 11:00 AM and 03:00 PM.	

```
import pandas as pd
data = {
  'temperature': [3, 2, 0, 1],
  'Air flow': [1, 3, 2, 0]
}
```

Based on the data of fuzzy logic 0 and 1, the analysis was done in Pandas library.

The two main criteria of temperature and air flow are considered as 0 and 1 phase data.

	temperature	air flow
0	3	1
1	2	3
2	0	2
3	1	0

Fuzzy logic is a method of reasoning that is similar to human reasoning and decision-making and includes all intermediate possibilities between yes and no.

	temperature	air flow
0	Use of plants	introversion
1	Central courtyard	East-west direction

The second stage of temperature is measured based on the two variables of the use of plants and the central courtyard.

	temperature	air flow
Q0	Use of plants	introversion
Q1	Central courtyard	East-west direction

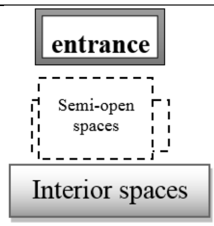
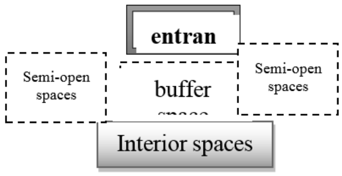
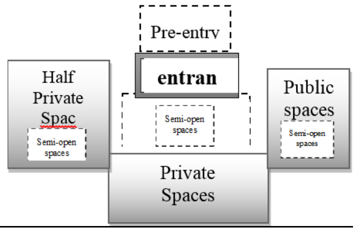
The third stage of the air flow is measured with two variables of introversion and building rotation in the east- west direction.

Fig. 3. Python-based criteria analyses and criteria

7. Recommended pattern

The recommended patterns related to the three building types have been stated in Table 5.

Table 5. Patterns use with SPSS

Typing	Period	Property	Pattern house
Type I*	1800	There is a space between the entrance such as a corridor and a corridor between the entrance and the interior spaces of the house. This paradigm implies the preservation of the privacy of the residents and spaces such as the central courtyard based on the need for climatic stability and air cooling.	
Type II*	1900	According to culture and religion, the hierarchy of entrances in this type is as follows: front entrance, main entrance, middle and inner space. In terms of localization, the architectural point of view is to determine the main spaces based on interior and exterior and to create porches all around the central courtyard, which causes climate stability	
Type I*II	2000-2024	This pattern is a combination of both extracted patterns. In this model, modernity and tradition are infused together and by placing the central space as the central courtyard and the balconies on the east and west sides, they greatly help to cool the air.	

8. Conclusions

Looking at tropical regions, we find that it has always been tried to design houses based on compatibility with the environment and climate, with the least samount of energy wastage and the least amount of use of technological devices in these areas. Also, by studying native residential patterns, we have achieved similar results in the direction of reducing energy consumption, and by combining the structural methods of these three styles of architecture, a common pattern can be achieved under the title of sustainability pattern. Among the methods used in the housing sustainability model, the following can be mentioned. .

- In general, in very hot climates, architects can design structures to absorb cooling breezes and allow warm indoor air to escape through openings in the roof during the cooler hours of the evening or night, and avoid installing windows. Large, south-facing sunshades can also be avoided.
- The type of placement and placement of the building should be such that it is inside the yard and can use more thermal energy.
- In order to use the proper air flow in the design of the building and in the joints, large openings should be considered so that the rooms are connected to each other and benefit from the cool wind flow in the summer and the heat of the sun in the winter.
- The use of high-thick walls in order to store heat energy inside the building, as well as materials that have a high thermal capacity, which should be given more attention in the south side.
- The maximum use of the depth of the ground is due to the two reasons of using the cooler air of the depth of the ground and the category of greater strength of the building.
- Creating conditions to facilitate air flow: for this purpose, giving the northwest-southeast direction to the building not only reduces the solar radiation energy in the hot season, but it can also reduce the air flow that is in the west and east directions to a large extent.

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Effects of water level changes of Lake Burdur and Lake Van on built environment

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Abstract. Van city center and Burdur city center are similar with their location on the lake shore. The concerns about climate change draw attention to the water level changes in Lake Van and Lake Burdur. In fact, they are very different in terms of topography and climate. Lake Van, the biggest lake of Turkey, is located in the Eastern Anatolian Region, which has continental climate. Lake Van Basin is surrounded by snowy mountains. Lake Burdur is located in the western part of Mediterranean Region and has the Mediterranean climate. Burdur Basin is at the western end of Taurous Mountans and full of small lakes, and Burdur Lake is the biggest one. However, Lake Burdur has been rapidly drying in recent decates. On the other hand, Van experienced a disaster in 1990s due to the increase in the water level of Lake Van. Some areas of the city center were evacuated. In the recent years, Lake Van also started to lose its water level which might cause other type of danger for the natural and the built environment. This study examines the effects of water level changes of Lake Burdur and Lake Van on built environment. The study is based on the review of the related literature, the written news, old photographs and site analysis.

Keywords: Built environment; Climate change;. Lake Burdur; Lake Van; Water level change

1. Introduction:

Climate change is a significant problem of today and might cause different results in the near feauture. Water levels of lakes are sensitive to variability and changes in climate. The frequency and severity of extreme climate events can increase and enhance floods and droughts in many regions (Ozdemir et al., 2023). Van and Burdur are the two city centers which are located in the lake side. Both lakes have been faced with climate change as flooding or drought in recent decades. Since these lakes are near the city centers, the effects of water level changes on built environment are in question. This study aims to examine the effects of water level changes of Lake Burdur and Lake Van on built environment.

Lake Burdur is located within the borders of Burdur and Isparta provinces in western Mediterranean Region. It is one of the deepest lakes in Turkey (maximum 110 m), with an average depth of around 40 m. According to the water level of 848 m, the total lake area within the borders of Isparta-Burdur is around 184.2 km2. An area of 38,125 ha in and around Lake Burdur was declared as a "Wildlife Conservation Area" in 1993. In 1994, the part of the lake covering approximately 50% (12,600 ha) was included in the “Ramsar Convention” list (Fig. 1) (WWF Türkiye, 2008). The Ramsar Convention is an international convention that aims to ensure the protection and sustainable use of wetlands (especially as Waterfowl Habitats). Burdur city center is located in the southwest side of the lake. The water level of the lake has dropped by 27 meters between the years of 1998 and 2008, and there has been a 27% decrease in its volume. Burdur Lake Management Plan Study was coordinated by the Ministry of Environment and Forestry and completed in 2008 (WWF Türkiye, 2008). The decrease in the water level of Lake Van is still continuing.

Lake Van is located within the borders of Van and Bitlis provinces in Eastern Anatolian Region. It is a volcanic barrier lake formed by the eruption of the Nemrut Volcanic Mountain, blocking the tectonic depression area in the region. It is surrounded by high mountains and plateaus. The Van Lake Basin, which cannot send its waters to the surrounding seas, is the second largest inflowing basin in Turkey after the Konya Basin. Lake Van, which is the largest lake in Turkey in terms of areal width, ranks 15th among the closed lakes in the world. Lake Van, which is considered as soda based on the high salt content of its waters, is also the largest soda lake in the world. The annual water potential is estimated to be approximately 3.5 billion m3 (Tarım ve Orman Bakanlığı, 2025).

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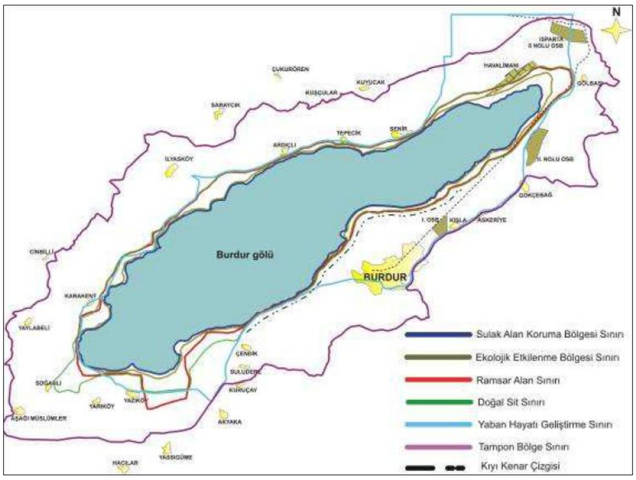

Fig. 1. Map of Lake Burdur and its significant conservation borders. Yellow area is city center, dark blue lines are wetland conservation borders, red lines are Ramsar convention border (WWF Türkiye, 2008).

According to bathymetry studies of Lake Van, the bottom elevation of the lake was determined as 1,195.42 m. Considering the long-term average lake water level (1,648.33 m) observed in the 67-year period between 1944 and 2010. When the low base elevation obtained from the lake bathymetry map, the deepest point of Lake Van is approximately 452.91 m and the average depth is 162.42 m. During the 67-year observation period between 1944 and 2010, the lake area of Lake Van varied between 3558.2 km2 (1962) and 3623.6 km2 (2996). Similarly, the lake volume was the lowest with 563.3 km3 in 1962 and the highest value with 575.0 km3 in 1996 (Tarım ve Orman Bakanlığı, 2020). In the years of 1990s, flow-through lake occurred in Van. On the contrary, Lake Van is facing with drouth in the current time. Although the extent of drought is not as high as in Burdur, the changes in precipitation in recent years are thought-provoking.

2. Materials ans methods

In this study, by considering the above mentioned georgraphical information about these two Lakes, water level changes are attempt to be analysed in terms of their effects on built environment. The research study is based on the review of relevant literature and site observations. The reviewed literature is mostly related to geographical reports and regulations of official institutions. Their effects on built environment are analysed by satellite map compariosons and site observations of the author with an experience for the last 10 years in Van and last 35 years in Burdur.

3. Lake Burdur and the effects of water level changes in Burdur City Center

Lake Burdur in located in the west side of Mediterranean Region in Anatolia. There ara lots of lakes in its surroundings. Hence the region is also called the District of Lakes. Some of these lakes have been faced with drought. Lake Burdur is one of the most affected lakes in this region. Fig. illustrates the changes of Lake Burdur from 1990 to 2020. It has almost lost its 1/3 area for the last 35 years. Since the Burdur city center is located on the lake side, the lost in water level affects city siluette, building qualities, besides the damages in the nature.

When 1990 and 2025 views of Lake Burdur (Fig. 2 & Fig. 3) are compared closely, it is seen that some new settlements added close to the area where the lake recedes. In Fig. 3, 1995 borders of the Lake Burdur is marked with blue lines on the 2025 satellite view. When compared with the 1995 satellite view (Fig. 2), it is clearly seen that “Isparta Süleyman Demirel Organised Industrial Zone” was constructed in 1992 -2000 close to the old borders of the Lake Burdur. Similarly, “Isparta Süleyman Demirel Airport” was constructed in 1997 in the old borders of the Lake Burdur. The old northern border of the lake was included in the provincial borders of Isparta. In the southwest border of the city, the new building of Burdur State Hospital opened near the old borders of the lake in 2023.

Fig. 2. GoogleEarth maps of Lake Burdur and the changes of water level, 1990, 2000, 2010, 2020.

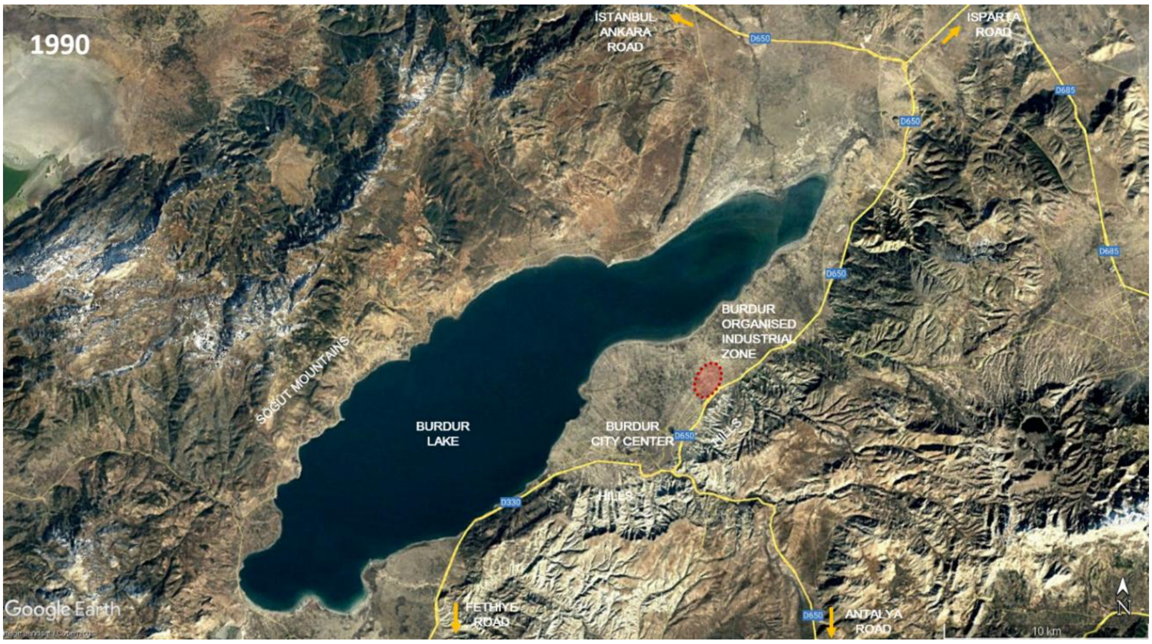

Fig. 2. GoogleEarth map of Lake Burdur, 1990. Marks are added by the author.

Fig. 3. GoogleEarth map of Lake Burdur, 1990. Marks are added by the author.

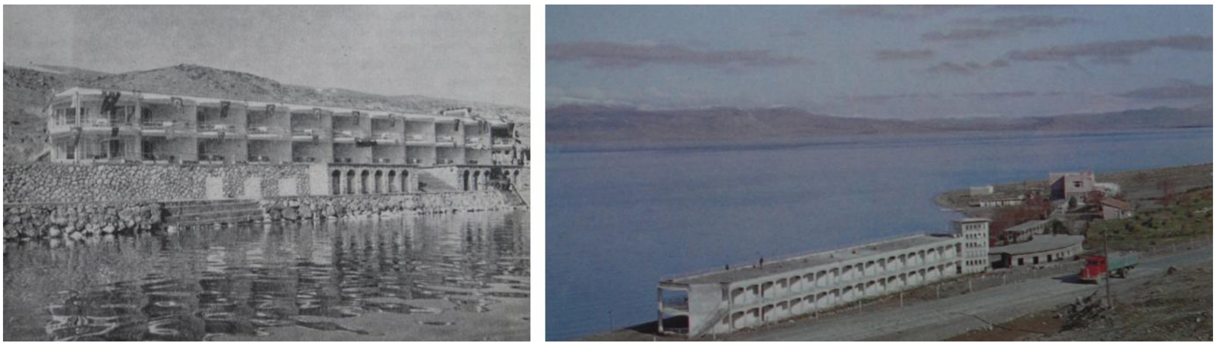

Fig. 4. Çendik Motel; north view and south view, 1967 (Burdur Valiliği, 1967).

Fig. 5. Çendik Motel; Googleearth 2025 view and the pier at its north, 2021 (TRT Haber, 2021).

The southwestern part of Burdur city centre, which is close to the lake side, is reserved for recreation areas, hotels, and summer villas. The negative effects of drought are most clearly and dramatically seen on these settlements. Fig. 4 illustrates the Çendik Motel which was opened by the Burdur Governorship in 1967. It is seen that the motel is located in the intersection of the intercity road and the lake side. The building, raised with a stone basement, rests on the lake border on its northern facade. On the other hand, Fig. 5 illustrates the water level changes in 2021 and 2025. Current lake border is far away from the motel. Although a long pier was constructed to reach the water level in 2019, the pier also became far and high from the current lake border (Fig. 5).

In addition to the water level decrease of lake Burdur, the WWF Türkiye (2008) claimed that the main problems of the Lake Burdur area are organized industry, factories and city sewage, which have insufficient treatment. Additionally, since Burdur is earthquake prone area, seismic risks might be also added to these problems. In the history of Burdur, two major earthquakes occurred in the last century; 1914 and 1971. Burdur is one of the cities through which a fault passes. The fault runs parallel to the mountains in the south of Burdur through the city and intersects with the lake border at the northwest end. The northern areas of the city close to the lake are soft ground which is not very suitable for constructions, so the city did not approach these sides. The area is mostly used as agricultural lands. In the past, the historical city center of Burdur was located on the hill where the *Ulu Cami* (Great Mosque) is located, which is in the center of the city today. Although there is no written information on this subject, it is possible that earthquake resistance and overflow of the lake were taken into account based on past experiences in the past settlement selection. However, today, while the lake waters are receding dramatically, it is seen that the constructions are shifting towards the old lake borders. This situation brings to mind the major damages caused by the constructions in the Amik Basin, which was established after the great losses experienced in Hatay after the earthquakes of February 6, 2023. While discussing the drop of the lake, the damage caused to nature and migratory birds, and the focus on saving the lake, the issue of the risks that may be brought by the shift of constructions towards the lake escapes attention.

4. Lake Van and the effects of water level changes in Van City Center

Lake Van located in the East Anatolian Region. It is surrounded by high snowy mountains, such as Erek, Artos, Nemrut and Süphan. The snows of the mountains feed important waterways. In the years between 1990 and 1995, Van had heavy snows than normal, and water level of Lake Van rose slowly day by day. This caused flows in Van city center, especially İskele Neighbourhood, and other lake side settlements. This water level changes cannot be clearly seen in satellite views of 1995 and 2025 (Fig. 6 & Fig. 7). However, old photographs can illustrate the effects of water level changes on lakeside settlements (Fig. 8).

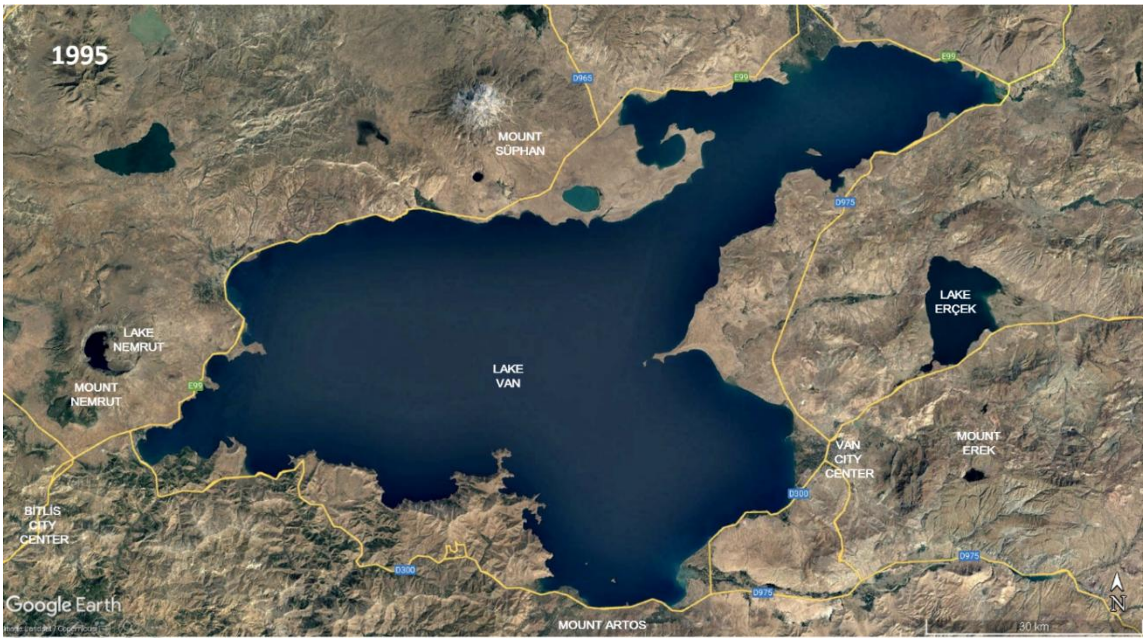

Fig. 6. GoogleEarth map of Lake Van, 1995. Marks are added by the author.

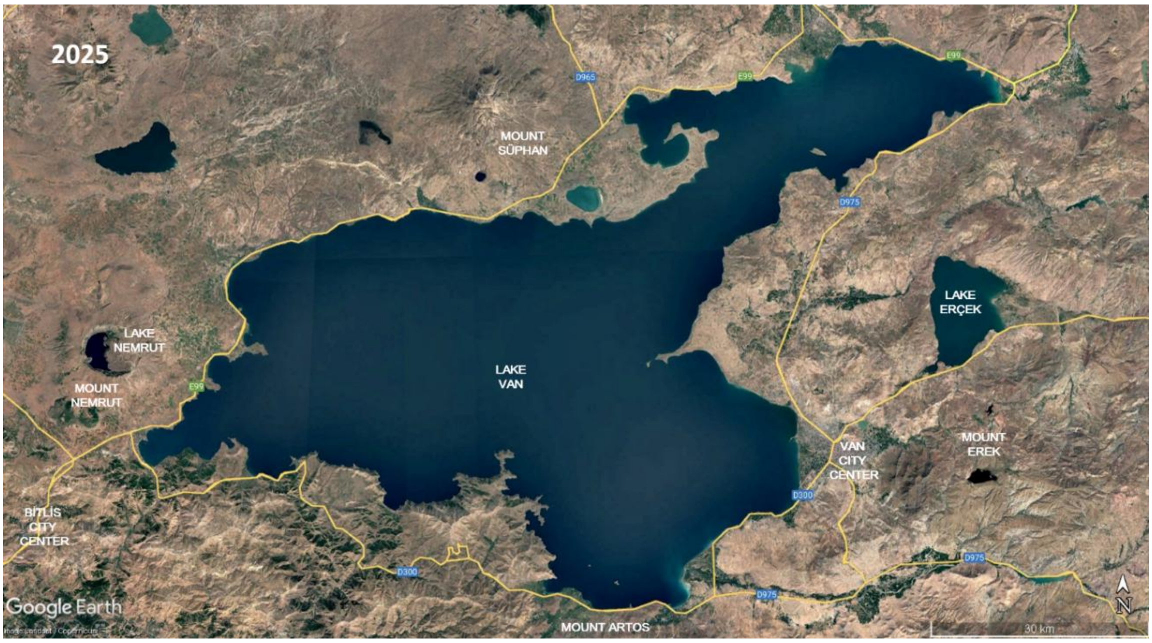

Fig. 7. GoogleEarth map of Lake Van, 2025. Marks are added by the author.

Fig. 8. Flood due to rising water level in Lake Van, İskele Neigbourhoud, 1995 (left: Deniz, 2003; right: Yıldız & Deniz, 2005).

Yıldız and Deniz (2005) studied the water level changes of Lake Van in 1990s and defined the effects on coastal settlements. Especially the rapid rises that had continued for several years in a row, caused great damage to the settlements, roads, agricultural areas and facilities belonging to public and private institutions around the lake. In the 58-year period between 1944 and 2002, as a result of the rise in the lake level, a total area of 52 km², 14.1 km² of which is urban areas, was occupied by lake waters. During this period, a greater or lesser amount of urban land was submerged in all the sides of Lake Van has been identified. A significant part of the 1413.7 hectares of urban land occupied by the lake waters belongs to the city center of Van (623 ha.). The level change caused great damage not only to coastal settlements and human facilities, but also to agricultural areas and wetlands around the lake (Yıldız & Deniz, 2005).

Yıldız and Deniz (2005) emphasised that the damages caused by the rapid rise in 1994-1995 were incomparably higher than in previous years (Fig. 9). A total of 1807 houses, 1178 of which were in urban spaces and 629 in villages, were exposed to disasters. Some of the dwellings were submerged in lake water, while others were affected by groundwater rise.

In 1995, the area was declared as a disaster area and İskele Neighborhood was evacuated. The Council of Ministers Decision No. 95/6925 of 8 June 1995 announced that 1655 meters level is the disaster level. Thus, city plans were revised and the 1655 meter level was declared as the disaster level where no new construction could be made. However, this decision became a matter of debate for those who had existing buildings and land in the area. With the decision of the Council of Ministers dated 20/02/2017, it was decided to reduce the lake water rise code from 1655 meters to 1653 meters and published in the Official Gazette. According to the decision published in the Official Gazette, the areas under the code of 1652 meters around Lake Van were considered as disaster areas. In the decision, it was stated that the existing structures between 1652 and 1653 meters codes will be preserved and no new settlements will be given. In addition, it was noted that in the buildings to be built on the 1653 meter code, the base code and the entrance codes such as buildings and parking lots are planned to be 1.00 meters above 1653 meters. With this decision, the Council of Ministers Decision No. 95/6925 of 8 June 1995 was also repealed (AFAD, 2025).

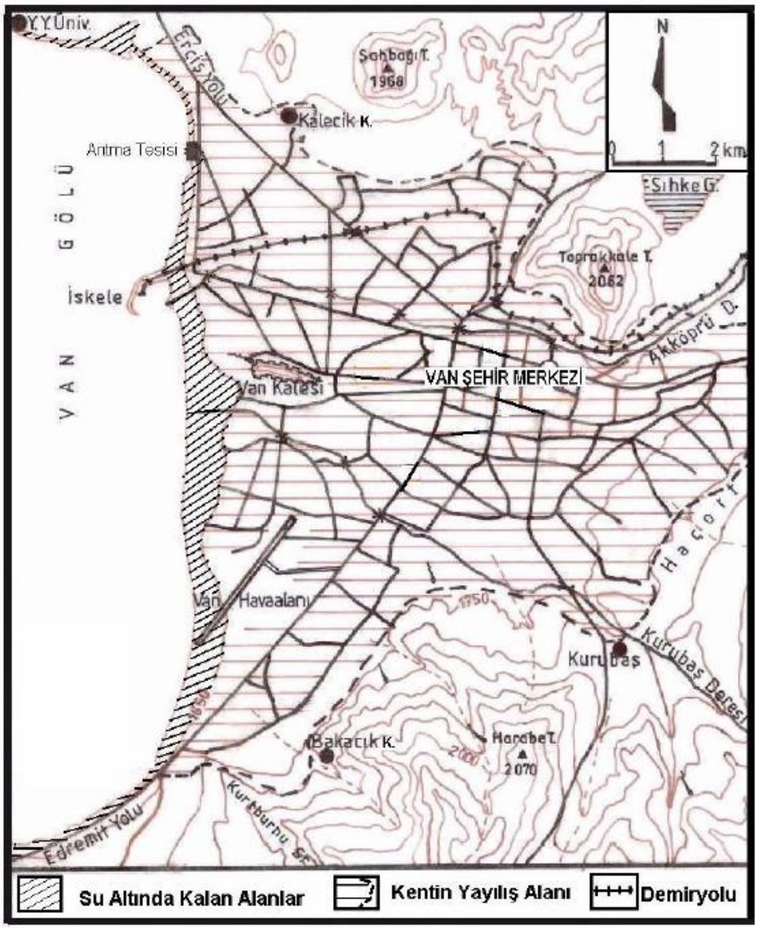

Fig. 9. Flooded lands in the Van city center, 1990s (Yıldız and Deniz, 2005).

Fig. 10. Retreat in Lake Van due to drought, 2023 (AA, 2023).

In the last few years, contrary to the 1990s, Lake Van is facing with drought risks (Fig. 10). It is not directly affected the built environment yet. However, the landscape of the lakeside is changing accordingly. Shallow and murky waters begin to appear along the lakeside. Since climate change might cause drought worldwide, the decrease in the level of Lake Van might continue. On the other hand, the IRAP report of Van AFAD stated that the problem of water level rise in 1990s, might most likely be repeated in the future. Hence, for the design and construction of new built environmets, both scenarios should be considered.

5. Results and discussion

The water level fluctuations observed in Burdur Lake and Lake Van have significantly affected the construction patterns of the cities and the city silhouette.

Burdur Lake has shrunk greatly in the last 35 years. The fact that approximately one-third of the lake area was lost from 1990 to 2025 led to the city center of Burdur being directly affected by this change. With the decrease in the water level, new residential areas and industrial zones were built in areas close to the lakeside within the city limits. This situation has adversely affected both the natural environment and residential areas. For example, the current status of Çendik Motel, which was built on the lakeside in the 1990s, has remained in a higher and more remote position with the receding water level. In addition, with the decrease in the lake level, social areas and touristic facilities by the water were also adversely affected.

Lake Van experienced a significant rise in water level in the early 1990s with the increase in snowfall. This rise has led to floods, especially in lakeside settlements such as İskele Neightbourhood, and the region has been declared a disaster area. In Van city planning, new arrangements have been made to reduce the effects of these floods, and an area up to 1655 meters has been banned from construction. However, with an amendment in 2017, the disaster level was reduced to 1653 meters. In recent years, due to the drought in Lake Van, the formation of shallow and turbid waters by the lake has led to significant changes in the landscape. Although this has caused the lake landscape in the city to change shape, it has not had a direct impact on the structures that have yet to be built.

It can be said that the water level changes around both lakes have significant effects on the residential areas. Fluctuations in the lake level have directly affected both the location of existing structures and the construction of new residential areas. In addition, the negative impact of touristic and recreational areas, in particular, has the potential to affect the local economy.

6. Conclusion

This research aimed to examine the effects of water level changes in Burdur and Van lakes on the built environment. The results show that the effects of climate change on residential areas and urban planning are becoming more and more apparent. The impact of climate change on the water levels of lakes plays an important role in both the management of water resources and the planning of residential areas. While the loss of water in Burdur Lake led to the construction of new industrial facilities and residential areas, the increase in the water level in Lake Van and the subsequent drought necessitated the rearrangement of existing structures according to the settlement plans. Water level changes have affected not only the settlements directly, but also the construction strategies depending on environmental factors. The structural changes made on the lakeside settlements in the city centers of Burdur and Van reveal the importance of sustainable management of natural resources.

This study provides some findings on the effects of water level changes on built environment of cities. However, it is clear that more research needs to be done in similar residential areas in the future. This research can help local governments bring lakeside construction and infrastructure projects more in line with climate change scenarios. In addition, developing structures that are more resistant to water level changes and strategic settlement planning will help prevent such negative effects in the long run.

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Study of aesthetic components for the revitalization of the old fabric of Tabriz, Iran (Case study: Tarbiat-e-Gharbi)

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Abstract. Old urban textures that have deteriorated and become abandoned spaces are considered abandoned and inefficient neighborhoods and settlements. When urban life in an area of the city stagnates for any reason and no effort is made to revive it, the urban texture of that area becomes worn out. The basic necessity of renovating and improving old and worn-out urban textures is to develop the living environment for humans. Economic, socio cultural, and other factors shape this necessity. For this reason, in this research, while recognizing the characteristics of the historical texture of Tabriz and the factors involved in the abandonment and destruction of some areas, an attempt is made to present urban design strategies and policies to promote the sustainability of this area and its improvement. Based on data extracted from different stages of the research and using a combination of various methods and tools for validating and evaluating models and patterns, the findings of this study have appropriate analytical power. In this regard, the set of indicators presented for the evaluation and analysis of aesthetic components affecting the improvement of the old urban fabric, with the aim of developing a conceptual framework for this process, has a desirable efficiency and is capable of comprehensively examining all dimensions and aspects of the research subject. The list of indicators and components identified in this study provides a systematic framework for categorizing and analyzing aesthetic dimensions affecting the improvement of the old fabric of Tabriz. This framework allows for the refinement of effective indicators and the separation of different dimensions related to the improvement process.

Keywords: Aesthetics; Revitalization; Old fabric of Tabriz; Western upbringing

1.Introduction:

The origin of beauty and the understanding of aesthetics has often oscillated between the two main poles of objectivism and subjectivism. Many efforts have been made to resolve the separation between objectivity and subjectivity by thinkers such as Husserl, Heidegger, and especially Norberg-Schulz, in order to apply both objectivity and subjectivity to phenomena through phenomenology. More recent philosophical analyses, adopting an interactive perspective, believe that the sense of beauty arises from the patterns that connect people and objects. For example, it has been suggested that beauty resides in the perceptual experiences of the perceiver and results from the interaction between the features of stimuli and the perceiver's cognitive and emotional processes (Dewey, 1934; Beardsley, 1958). This view aligns with the idea that aesthetic qualities are not inherent but are credited to the experience of observers as they respond to the objective and formal features of artworks (Beardsley,1958). It has also been said that although beauty is not an objective matter existing independently within the artwork itself, it finds meaning in the realm of shape and form and is analyzed by the mind. Every artwork has a quality that is independent of the realization of its meaning and content in the mind of the audience, and it is not confined to the emotions of the viewers. Therefore, an artwork, through the autonomy of its form, can elicit various emotions in audiences who are unpredictable and may offer different interpretations of their perceptions (Norouzitalab, 2008). In fact, a reasonable (and common) resolution to the objective subjective debate in evaluating aesthetic quality acknowledges that aesthetic quality is a joint product of visible characteristics that interact with related perceptual, cognitive, and emotional psychological processes in the human observer (Lothian, 1999). Based on this, according to another categorization (Golkar, 2000) regarding the quality of urban design which can also be generalized to

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the component of urban aesthetics—the threefold theories concerning the existence of urban design quality are as follows:

- As a quality or attribute inherent in the physical environment and existing independently of the observer
- As a subjective and taste-based category constructed by the observer and unrelated to the structure and physical characteristics
- As a phenomenon or event that is formed in the course of an exchange between the tangible and physical characteristics of the environment on one hand, and the cultural codes and mental capacities of the observer on the other (Golkar, 2000).

It has been examined from an objectivist perspective, and for this reason, urban theorists and designers have proposed numerous formal criteria for creating beautiful places (Pakzad & Saki, 2014). Despite differences among theorists' views on aesthetics, most of the criteria expressed within the objectivist approach are taught in the fields of urban planning and architecture. However, in addition to these criteria, perceptual studies with a subjectivist approach have been conducted, which focus more on people's evaluations of the beauty of various spaces, in order to examine aesthetics and the characteristics of beautiful spaces from the perspective of the public.

With the rise of perceptual aesthetics research and the publication of their findings, the differences between earlier evaluations of beauty and these new studies became clear, prompting researchers to further explore these distinctions (Chen et al., 2009). Since then, various methods have been employed to address aesthetic issues; among them is aesthetics with an approach focused on public preferences (Keshtkaran et al., 2017). The old urban fabrics that have become worn out and abandoned are considered derelict and inefficient neighborhoods and settlements. When urban life in an area of the city declines for any reason and no effort is made to revive it, the urban fabric of that area enters a process of deterioration (Andalib & Haj Akbari, 2008: 23).

The concept of urban deterioration can be understood as the decline of the social, economic, and physical conditions of the urban fabric (Rosmani,2008: 9). Therefore, urban deterioration is the result of various factors that, over time, must be prevented from spreading through greater care and actions such as improvement, renovation, and reconstruction. The fundamental necessity of renovating and improving the old and deteriorated fabrics of cities lies in the development of the human living environment. This necessity falls under economic, socio-cultural, and other essential factors (Shamaei & Pourahmad, 2010: 43). Hence, urban deterioration is a national issue and one of the serious problems and important priorities in the country's development planning, which must be addressed with comprehensive determination and a committed outlook. For this reason, this study, while identifying the characteristics of the historical fabric of Tabriz and the factors involved in the abandonment and destruction of certain areas, seeks to provide strategies and urban design policies aimed at enhancing the sustainability of this area and its improvement.

Mansouri (2023), in the article Struggle with Aesthetics, emphasized the importance of what is considered "beautiful," which has been discussed since the fifth century BC when Plato distinguished between the rational and logical and the good, emotional, and perceptual. The passage through time and the experiences of various societal transformations opened the way for this phenomenon—before being scientifically defined and documented in philosophical literature and while societies held an intuitive understanding of it—to enter academic discourse. Afterward, the understanding and evaluation of the beautiful became known in the form of the science of "aesthetics," which, beyond being confined to the world of art and referring to subjective dimensions, gained an objective and functional scale. A well known example of this transformation in urban literature is the term "urban aesthetics." In another article, Daemi and colleagues (2023) examined the role of tourism dimensions in the sustainable regeneration of the old fabric of Yazd, with the aim of urban regeneration as an approach to updating the old fabric of the city—while preserving neighborhood identity and authenticity— and responding to daily needs and sustainable urban development. For this purpose, the present study, using four main tourism variables, investigated the role of urban tourism dimensions in the regeneration of the historical fabric of Yazd. The goal of this research is to understand the mutual relationships between urban tourism and the regeneration of the old fabric of Yazd.

2. Theoretical foundations

The understanding of aesthetics is essentially visual and dependent on beauty. Despite the growing attention to the effects of the visual qualities of the environment on sustainability and the enhancement of quality of life, many questions in the field of aesthetic studies remain unanswered. A review of the urban aesthetics literature over the past half-century shows how discussions on aesthetics have shifted from being visually and artistically focused to having perceptual and semantic tendencies. In this section, the definition of the terms "beauty" and "aesthetics" is first addressed, followed by an examination of aesthetic approaches (objectivist and subjectivist approaches), methods for evaluating beauty, the fundamental perspectives in urban aesthetics, key approaches in urban aesthetics (expert-centered and people centered), and finally, the principles of urban aesthetics are discussed.

2.1. Beauty and aesthetics

In the Moein Dictionary, beauty is defined as a state and quality. Beauty is the order and harmony that exists along with grandeur and purity in an object, stimulating the intellect, imagination, and higher desires of humans. In the Dehkhoda Dictionary, aesthetics is defined as the recognition of beauty and a branch of psychology whose aim is to identify beauty and art (Behzadfar & Ilka, 2009). The term "aesthetics" or "esthetic" is derived from a Greek word meaning sensory perception. In the 18th century, Alexander Baumgarten used this term in the context of the perception and evaluation of beauty. This new term gained widespread use among English speakers from the mid-19th century onward. In some modern philosophical movements, there is a tendency to use the term "aesthetics" in a broader sense than merely the evaluation of beauty—referring also to the nature of attraction and other aesthetic qualities in a comprehensive view. Khakzand et al. (2014) state that the Greek word Aisthetikos means sensory perception, and the word Aisthea includes what is perceived. Ahmadi (1996) mentions that the science of aesthetics also examines the structure of methods for sensing the environment and the individual's position in the process of this perception (Groter, 1996).

Aesthetics is a science that deals with the nature and essence of beauty. This question has received two different answers in the fields of art and philosophy; philosophy responds to questions such as whether the roots and constitutive factors of beauty are absolute or relative, their nature, and\ their relation to other sciences. In art, it refers to the rules and systems that govern the shaping of artworks in the process of their creation. Identifying examples and manifestations of beauty is a product of human artistic output. By examining beautiful examples in the artworks of each land, one can understand the general criteria governing them (artistic aesthetics) (Mansouri, 2012). Aesthetics, or the science of what is beautiful, studies a set of principles that make the viewer focus their attention on the work and enjoy the sense of unity and harmony in their sensory perceptions (Atashin Yār, 2012). Aesthetics, which was once a branch of philosophy, is in the contemporary era a combination of philosophy, psychology, and sociology of art (Naghizadeh, 2002).

2.2. The objective aesthetics versus subjective aesthetics

An examination of the existing approaches regarding the nature of aesthetics reveals two main perspectives: objective and subjective. Many views have been proposed regarding whether beauty is subjective or objective. There are differing opinions about whether aesthetic judgment pertains to the sender or is an interpretation by the receiver. Significant challenges have been made to bridge the gap between objectivity and subjectivity by figures such as Husserl, Heidegger, and especially Norberg-Schulz, in order to apply both objectivity and subjectivity to "things" based on phenomenology. However, what is commonly understood from the term Aesthetic today is based on both objective and subjective dimensions of beauty. Studies show that in relation to these two approaches in the urban landscape, the objective approach was initially dominant, followed by a growing focus on subjective approaches. For instance, picturesque, with its architectural emphasis on visual and artistic aspects of the landscape, such as attention to human scale diversity, naturalism, and organic order in form and composition, as well as color, was popularized by figures like Zittel, Gibert, and Halperin. Meanwhile, gradually, urban beauty shifted from the domain of objective, emotional, and specialized focus on visual qualities—such as form, color, and texture—to the domain of perceptual studies of the subjective experience of th urban environment.

2.3. The degree and gradation of beauty

The degree of beauty is the pleasure felt by the perceiver, which arises from the desire to repeat individual experiences within the realm of internal observation. This desire is formed in humans through experience in any given field. The degree of beauty can also be understood in terms of quantity and quality, with the artistic quality encompassing the criteria for evaluating aesthetic beauty, and the artistic quantity referring to criteria related to the magnitude and extent of beauty. There have been fundamental efforts throughout the history of art and architecture to define and determine the quantitative aspect of beauty, expressing beauty using mathematical formulas. Another measure of aesthetic criteria can be based on values such as "trend" and "style," where the valuation of beauty is divided into levels from authentic to fundamental, linked to the foundational "aesthetic values" (Behzadfar, Elika,1391). Questionnaire studies are widely used as tools to examine people's attitudes and preferences. The advantage of questionnaires is that they allow the gathering of opinions from a representative group of people within a short period, providing an opportunity to evaluate attitudes across individuals from diverse socio-economic and geographical backgrounds.

In the evaluation of the aesthetic quality of landscapes, "Aryaza" and his colleagues believe that landscapes have inherent or objective beauty, although the viewer's response is subjective. Based on the views of "Briggs" and "Franz," they believe that there are two main methods of evaluation: Direct Methods: People's scene preferences regarding landscapes are compared to reach a consensus. With this method, Aryaza and his colleagues sought to evaluate the scene preferences of observers. They used images of landscapes for this purpose. This approach was based on the assumption that aesthetic judgments from images provide a suitable criterion for the beauty of real landscapes. Indirect Methods: Landscapes are evaluated based on the presence or intensity of defined characteristics. These methods bring together the components of landscapes to derive an overall value. In this method, it is believed that the entire scene is a collection of its components. However, some researchers have criticized this approach for its tendency towards subjective theories in evaluating the components of landscapes. Furthermore, this method does not include the interactive effects of each of the components.

"Arthur" and his colleagues used the terms of general priority models and descriptive list methods. These classifications are similar to the classification of direct and indirect methods. "Shafer" and his colleagues proposed a combination of descriptive methods and holistic models such as psychophysical models and surrogate component models. In recent years, this approach has gained attention due to the use of statistical techniques to determine the relationships between landscape components and scene preferences (Karimi-Moshaver, 1392).

Urban Aesthetics The realm of the presence and manifestation of beauty is infinite and stretches between human and the world, between past and future, between object and subject, between "me" and "you," and between reality and imagination. Therefore, the manifestation of beauty possesses an astonishing variety. Nevertheless, the domain of beauty can be divided into four main areas, as shown in the attached framework. Main areas of the manifestation of beauty:

- Beauty in the appearance of nature
- Beauty in work, production, and industry
- Beauty in artistic works
- Beauty in the human-made environment

These four areas are interconnected and interact with each other, reflecting a kind of unity in diversity. The study of the nature and functions of beauty in different fields is the subject of aesthetics, which itself is divided into various branches such as philosophy of beauty, psychology of beauty, environmental psychology, philosophy of art, art history, art criticism, etc. However, here we focus on the study and role of beauty and aesthetics in the urban environment, which belongs to the fourth area (the human-made environment). From the perspective of sociology and psychology, the city is the most complex human settlement in which the broadest human-environment relationships are categorized into three main components: spatial perception, sense of belonging, and sense of beauty.

- Spatial perception: understanding the environment and feeling spatial identity
- Sense of belonging: creating attachment and memory toward the environment
- Sense of beauty: feeling pleasure and emotional harmony with the environment

These three phenomena are organically connected with one another and together lead to the creation of satisfaction, comfort, safety, and pleasure for human beings. In fact, without spatial perception and a sense of spatial identity in the urban environment, it is not possible to develop attachment and a sense of belonging to it. And without a sense of belonging, one cannot attain the feeling of beauty and aesthetic pleasure. Any disruption or failure in this process results in feelings of ugliness, suffering, and tension. The aesthetics of art differs from urban aesthetics, although there are also connections between them. An important point in the aesthetics of the urban environment or urban landscape is the spirit and character of the perceiving individual. In the 18th century, the concept of beauty had a psychological dimension. This means that the viewer was also considered part of the beauty perception process and played a fundamental role in it. The perception of beauty is to a large extent considered a subjective matter. That is, beauty is not a quality of an objective phenomenon independent of its perceiver, but rather a value that is added by the perceiving individual to an objective entity such as a natural landscape, a building, a painting, a poem, or a piece of music. Therefore, what is considered beautiful or ugly depends on the individual's opinion.

In the perception and evaluation of the beauty of an environment and urban landscape, in addition to the usual and common physical criteria such as rhythm, order, proportion, etc., many factors and criteria within the realm of semantic perception also influence the assessment of beauty. Among them, one can point to the presence of nature and natural elements in human-made spaces, which, in addition to softening the environment and preparing it to play the role of a desirable space, is one of the main methods of conveying beauty to the environment — in other words, creating a beautiful space. A key factor that ultimately gives an urban landscape its charm and beauty is the life present within it. In landscape architecture, two elements are addressed: one is the urban space, and the other is the natural space. Natural beauty is perceptible unintentionally and spontaneously, but the urban landscape can only be perceived when it is free from chaos and possesses unity and harmony (Javadi, 2013). District 8 of Tabriz is located in the city center of Tabriz and is adjacent to Districts 4, 10, 11, 2, and 3, and is, in a way, surrounded by these districts. The area of this district, which is also considered the smallest in terms of size, is 388.4 hectares, and its population is28,006 people. Meanwhile, the per capita total land use in this district is 138.7 square meters. This district, with a population of 28,006 people, has about 18 hectares of service land use up to the regional level, and its total per capita service land use amounts to 6.43 square meters. The highest share of service land use in this district pertains to educational, administrative & law enforcement, and religious uses, amounting to 7.3, 3.3, and 2.8 hectares respectively, which together account for approximately 75% of the district's services. According to standard per capita criteria, there is a total shortage of about 21.4 hectares of services throughout the district, of which about 34% relates to a shortage of neighborhood-level services,48% to a shortage of district-level services, and about 18% to a shortage of regional-level services. Based on the collected data, the highest service shortages in the district are related to park and green space uses, healthcare services, and urban facilities, amounting to approximately 11.6, 2.5, and 0.5 hectares respectively. At the neighborhood and district level, the greatest shortage relates to healthcare land use, totaling about 1.9 hectares.

3. Location of Western Tarbiat Street in the old texture of Tabriz

Tarbiat Street is located in a neighborhood of the same name in the city center, within the old urban fabric, and to the south of the historical bazaar. Spatially, it forms a commercial system. Its length is 283 meters and its average width is 15 meters. This street is bounded on the northwest by Jomhouri Street and on the southeast by Ferdowsi Street. Before the construction of this street, the area served as a passage and was known as a famous branch of the Silk Road or Ipak Yolu, and it held particular renown (Khamachi, 2005). In those times, it was the passageway for the city's residents from the Nobar, Maqsoudieh, and Charandab quarters and the "Laleh Beig" path to the Darbandi Gate toward the Shaterban bazaar and the residence of Ali Qapu. On the other side, it also functioned as a route and access to the Shishegar Khaneh bazaar and later to Haft Kachal Square, which today is known as the Tarbiat-Ferdowsi intersection (see Fig. 1).

3.1. Historical and cultural characteristics of Tarbiat Street

Tarbiat Street has a historical background and an old urban fabric, housing several historical landmarks. This historic axis corresponds with a route that begins at the Nowbar Gate and connects on the other side to the Tabriz Bazaar. Nowbar Gate served as one of the external access points to the Tabriz Bazaar through this passage. The Tabriz Bazaar, with itsncenturies-old heritage, has long been a central hub for the city's commercial and economic activities.

Fig. 1. Position of Tarbiat passage with significant urban spaces

Table 1. Location of the Tarbiat passage in relation to the Nowbar Gate, Tabriz, Iran (Naqsh-e Jahan Pars Consulting Engineers, 2007)

Neighbourhood	Area	Population	Households	Role	Potential
Trabiat	26.6	1102	331	- Commercial with city-wide function - Workshop with urban, residential, and neighborhood-level function	- Proximity to the old city core - Presence of historical-cultural elements - Housing for middle-income populations - Rrelatively large average residential land plots

Fig. 2. The position of Tabriz Passage in relation to the Nowbar Gate (NaqshJahan Pars, Consulting Engineers, 2007)

3.1.1. Physical-spatial characteristics of Tarbiat Street

One of the key components of urban studies, especially at a micro-scale, is the study of physical structure. The physical form serves as both the basis for understanding and intervention in urban planning. In other words, although urban planners and designers analyze various dimensions ranging from history and culture to population and economy to understand a study area, the physical structure is ultimately what they can make decisions about and influence directly. Therefore, when the physical structure becomes the subject of study, it demands the utmost attention to detail from broad patterns to precise elements.

3.1.2. Access map and land use structure map

The architectural structure of Tarbiat Street, in terms of its physical and spatial characteristics, belongs to the architectural tradition of the late Qajar period, often referred to as the “Era of Architectural Transformation.” This period coincides with the arrival of automobiles and the introduction of streets into the traditional fabric of Iranian cities, which laid the foundations for modern street architecture and gradually introduced a new identity into this tradition. In terms of volumetric content, buildings from this generation typically have a two-story structure. The ground floor is primarily used for commercial purposes, while the upper floor is either residential or accommodates business and trade offices (Zekavat, 2010: 128). This era also marks the beginning of outward-oriented architecture, which, although greatly influenced by local criteria, still retains a strong indigenous character. It is no coincidence that the most valuable buildings of this period, representing high-quality architecture, are prominently located along major streets. This valuable architecture does not merely follow external concepts but localizes imported ideas and fully leverages the potential of the location to express its own values.

Fig. 3. Physical-spatial characteristics of Tarbiat Street
(Left: Map of access and structure, Right: Map of existing land uses)

4. Research Methodology

This research is of a quantitative nature. Quantitative research should be viewed as a systematic and scientific method of inquiry that operates based on the collection of data and information about the phenomena under study.

In this method, after categorizing and preparing data for processing, statistical, mathematical, or computational techniques are employed to model the behavior of phenomena.

Quantitative studies use sampling methods to focus on a portion of the target population and collect the required information through questionnaires (either online or paper-based). The statistical analysis of such data leads to the results of the quantitative research. These results, once accurately interpreted, allow for the prediction of a product or service's future based on the proposed model, making it possible to implement appropriate changes.

In this study, to evaluate citizens' opinions and prioritize the importance of each factor influencing aesthetics in the revitalization of the historic fabric of Tabriz, the Friedman test was used. Citizens were asked to rate each proposed aesthetic component based on the Likert scale. The Friedman test is a non-parametric statistical tool used when the data are measured at an ordinal level. It enables the analysis of two-way variance through ranking and comparison of average ranks among different groups (Habibpour & Safari, 2012). This method allows the researcher to assess the importance of each component entirely based on the opinions of the sample, independently of the relationships between variables (i.e., without assuming dependencies between independent and dependent variables).

To interpret the results of the test and determine whether there are statistically significant differences in the average opinions of citizens regarding the components, the results shown in Table 2 are used. With a test value of 150.862 and a significance level less than0.01, it can be concluded that the importance and role of each factor in defining the aesthetic concepts in the revitalization of Tabriz's historic fabric are statistically significant (p-value: 0.000). In addition to significance, the Friedman test also helps identify the ranking differences of the components from the perspective of respondents, thereby enabling the prioritization of criteria. In other words, the test shows which components have higher or lower average ranks. For this purpose, the results shown in Table 3 under the title "Ranks" can be used.

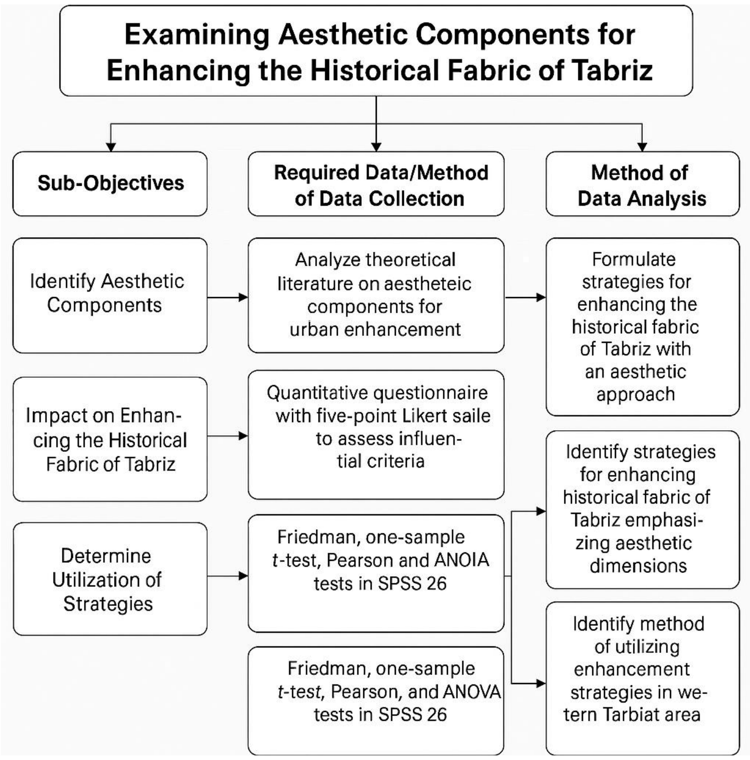

Fig. 4. Research methodology process

Table 2. Friedman test statistics

Value	Intact
N	100
Chi-Square	150.862
Df	32
Asymp. Sig.	0.000

Table 3. Mean rank assessment of key aesthetic components for revitalizing the historic fabric of Tabriz

Component	Mean Rank
Number of noisy land uses	17.34
Satisfaction with the compatibility of land uses in the area	15.27
Availability of gathering spaces and group activities	14.16
Variety of recreational activities	14.07
Quality of public restrooms in the area	13.42
Attractiveness of the space during the day	14.75
Attractiveness of the space at night	17.68
Spaces for children's play	15.43
Suitability of existing land uses for the area	17.75
Legibility of land uses	18.80
Quality of surface water drainage	17.02
Variety of urban furniture	15.96
Visual coherence of façades in terms of proportions	15.12
Design of shop windows	17.77
Identity-based detailing in the design	19.05
Unobstructed visibility of surroundings	16.86
Number of high-rise constructions	17.95
Use of local cultural symbols in urban signage	13.85
Quality of access routes to the area	18.45
Quality of existing buildings	17.49
Quality of street paving	14.03
Pleasantness of the spatial experience	17.45
Attention to human scale	19.95
Attention to balance and sequence in design	18.47
Noise pollution	19.68
Air pollution in the area	19.04
Diversity of green space usage	16.29
Presence of native and historic vegetation	15.47
Climate comfort	16.90
Traffic and car parking, social interactions in the area	17.20
Sense of safety	18.65
Sense of nostalgia	21.32

5. Interpretation of Findings

As shown in Table 3, based on the results of the Friedman test and the mean ranks of components influencing the revitalization of the historic fabric of Tabriz, the top three components with the highest mean ranks are:

- Sense of Nostalgia (21.32): This component, having the highest mean rank, highlights the deep importance of fostering emotional and cultural connections between citizens and the historical urban environment. A strong sense of nostalgia can reinforce place identity and attract people to the area.
- Attention to Human Scale (19.95): Designing with human scale in mind ensures that the environment aligns with people's needs and expectations, which significantly enhances comfort and satisfaction.
- Noise Pollution (19.68): This factor reflects the negative impact of disturbing sounds on the overall experience of the space. Reducing noise pollution directly contributes to improved quality of life and urban tranquility. The findings also show that components such as sense of safety (18.65), quality of access (18.45), and balance and sequence in design (18.47) are considered highly important by citizens.
- A sense of safety is crucial for shaping sustainable urban environments.
- Access quality reflects the role of infrastructure in improving connectivity and ease of access to historic areas.

Balance and sequence in design emphasize harmony between environmental elements, leading to a more cohesive spatial experience. Conversely, the three components with the lowest mean ranks are:

- Quality of public restrooms (13.42): This basic need was ranked lowest, possibly due to citizens prioritizing broader and more influential urban factors.
- Variety of recreational activities (14.07)
- Availability of gathering spaces and group activities (14.16)

These results suggest that while these elements are necessary, they are perceived as less critical compared to more identity-based and experiential components like nostalgia, safety, and urban scale Interpretation of Lower-Ranked Components. The quality of street paving, compared to other issues, has received relatively less attention.

The low ranking of “use of urban signs inspired by local culture” (13.85) may reflect a lack of public awareness or limited appreciation of the role cultural symbols play in enhancing the sense of place.

This lower perceived importance might also indicate the current state and performance of these cultural and functional infrastructures. However, overlooking such components can negatively impact citizens’ overall experience of the urban environment. Basic needs such as street paving quality and public restrooms should not be neglected in the revitalization process. Overall, findings suggest that emotionally driven components (such as sense of nostalgia) and environmental factors (such as noise and air pollution) carry higher priority in the minds of citizens. In contrast, more functional or secondary elements (like restrooms and paving quality) are ranked lower in terms of importance. This reveals that revitalization efforts should place greater emphasis on cultural and psychological needs of citizens, while still addressing essential infrastructural requirements. The following is the mean and the standard deviation obtained for all the More components of the review as shown in Table 4.

Table 4. The mean and standard deviation of each component affecting the old texture of Tabriz city, Iran

Component	Mean	Standard Deviation
Number of noisy land uses	2.64	1.030
Satisfaction with land-use mixing	2.48	0.904
Presence of gathering spaces and group activities	2.43	0.902
Variety in recreational activities	2.30	0.835
Presence of gathering spaces and group activities	2.43	0.902
Variety in recreational activities	2.30	0.835
Adequacy of public restroom facilities	2.28	1.026
Daytime spatial quality	2.37	0.939
Nighttime spatial quality	2.74	0.906
Availability of children’s play spaces	2.42	1.156
Suitability of existing land uses for the area	2.72	0.944
Legibility of land uses	2.83	1.074
Adequacy of surface water drainage system	2.63	0.849
Diversity of urban furniture	2.50	0.959
Façade design regarding visual proportions	2.48	0.969
Design of commercial storefronts	2.69	0.734
Identity-oriented detailing in local design	2.83	0.877
Unobstructed visual clarity of surroundings	2.70	1.059
Number of high-rise constructions	2.78	0.970
Use of local cultural urban symbols	2.32	0.839
Quality of accessibility to the area	2.80	1.044
Quality of existing buildings in the area	2.71	1.008
Quality of street paving	2.35	0.957
Noise pollution level	2.96	1.00
Air pollution level	2.89	1.034
Diversity in the use of green spaces	2.52	1.020
Presence of native and historic vegetation	2.46	1.058
Consideration of climatic comfort	2.62	0.962
Traffic and parking conditions in the area	2.83	1.256
Level of social interaction in the area	2.67	0.842
Sense of security	2.84	1.032
Sense of nostalgia	3.12	0.820

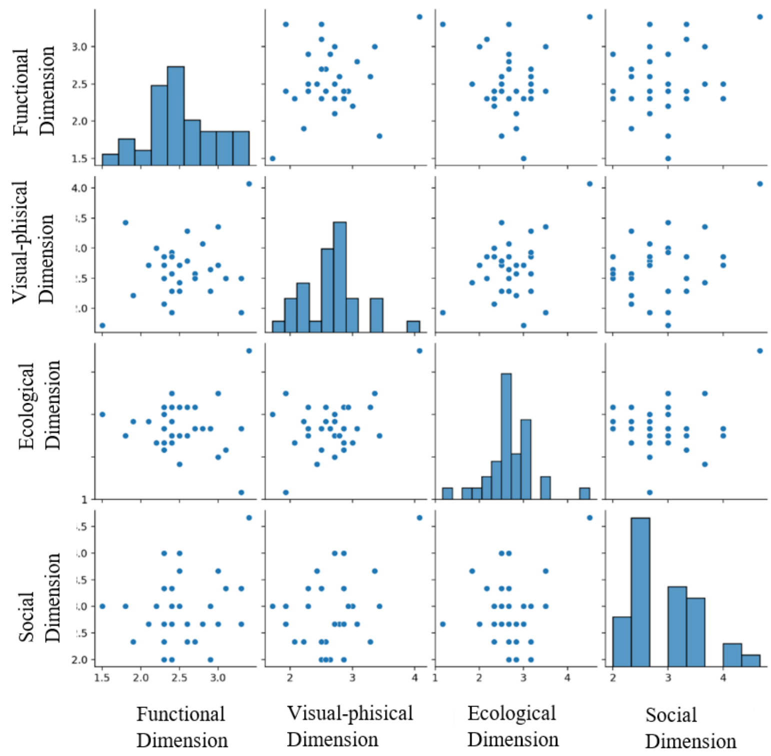

Fig. 5. The matrix charts of the solidarity relationship relationships between the dimensions investigated

6. Conclusion

Based on the data collected through various stages of the study and the use of a combination of methods and tools for validating and evaluating models and frameworks, the findings of this research possess strong analytical and generalizability capabilities. In this context, the set of indicators presented for assessing and analyzing the aesthetic components influencing the renovation of historic urban fabric provides an efficient and comprehensive framework for conceptualizing this process. The identified list of indicators and components offers a systematic structure for categorizing and analyzing the aesthetic dimensions impacting the revitalization of the old fabric of Tabriz. This framework enables the refinement of influential indicators and the distinction of various dimensions related to the renovation process. To propose strategies for renovating the old fabric of Tabriz with an aesthetic approach, the analysis of data and findings reveals that various factors across functional, visual-physical, ecological, and socio-cultural dimensions—have diverse impacts on space quality and the overall desirability of the area. The results of the Friedman and Pearson tests specifically highlight the indicators that should be considered in developing the strategies including:

6.1. Functional strategies

Functional dimensions are among the most important factors in the renovation of old urban fabric. The Friedman test results indicate that indicators such as land use legibility (18.80), suitability of existing land uses for the area (17.75), and the desirability of spaces at night (17.78) play a vital role in enhancing the efficiency and performance of the area. The proposed strategies include:

- Improving the legibility and compatibility of land uses through systematic design and revision of incompatible functions
- Designing spaces with an emphasis on efficient performance to enhance spatial experience and foster a sense of belonging
- Separating noisy land uses and introducing mixed-use developments aligned with urban needs—such as integrating residential, commercial, and cultural functions— can increase social interaction and reduce environmental issues. In this regard, noisy uses should be located away from residential areas and placed in designated zones.
- Spaces for gatherings and social interaction: Designing areas for social gatherings and group activities—such as parks, plazas, and cultural centers—can foster social interaction and a sense of place. Especially, public spaces like cultural centers and cafes with thoughtful design can promote cultural and artistic activities in the old city fabric of Tabriz.

- Desirability of space during day and night: Urban improvement should include spaces that are attractive and functional both during the day and night. Appropriate lighting in public spaces at night, shaded areas during the day, and overall enhancement of urban scenery can add to the appeal of such environments

6.2. Visual-physical strategies

Indicators such as the design of commercial storefronts (17.77), attention to the visual proportions of facades (15.12), identity of architectural details (19.05), and the quality of access to the area (17.75) demonstrate the significance of visual-physical dimensions in the renovation process. The findings also confirm a positive and significant correlation between these dimensions and sociocultural aspects (r =0.236*). Based on this façade design. Emphasizing Tabriz's history and cultural heritage in spatial design can attract tourists and enhance the sense of belonging among residents. Renovating and upgrading building facades using visual harmony and local materials such as stone, wood, and brick can help revive the visual identity of Tabriz. Combining modern facades with traditional and vernacular architectural patterns will give these spaces a unique identity. Storefronts should be designed to harmonize with the city's historical architecture. Using natural materials, local colors, and traditional styles in the design of storefronts can significantly improve the visual and commercial appeal of the area. Attention to design details—including urban furniture, signage, and markers—can strengthen the area's identity. Incorporating cultural symbols and motifs of Tabriz into spatial design can showcase the region's cultural heritage while enhancing spatial aesthetics.

6.3. Ecological strategies

Although the Pearson test results show no significant correlation between ecological dimensions and other aspects, indicators such as the presence of native plants (15.47), consideration of climatic comfort (16.90), and the diversity of green spaces (16.29) highlight the necessity of improving environmental quality. Strategies include:

- Increasing vegetation cover with an emphasis on native species better suited to the local climate.
- Optimizing open space design to reduce air and noise pollution (especially considering the relatively high average levels of both in the area).
- In light of Friedman test results indicating existing pollution, developing green spaces and implementing modern public transport systems can reduce air and noise pollution. Moreover, urban design should prioritize reducing pollution sources, especially in high-traffic areas.
- Climatic design measures, such as creating natural shading and using heat-resistant materials, can offer more comfortable conditions for residents and visitorsand help reduce energy consumption in urban spaces.

6.4. Socio-cultural strategies

Socio-cultural dimensions are among the key components in renovating historical urban fabric. Indicators such as social interaction (17.20), sense of security (18.65), presence of gathering spaces (14.16), and the memorability of space (21.32) play a significant role in enhancing urban quality of life. Designing spaces for cultural, artistic, and social activities can help foster social interaction. Establishing cultural centers, exhibitions, and communal spaces in the Western Tarbiat area can increase the attractiveness of this district for both residents and tourists. Accordingly:

- Create appropriate public spaces for social interaction, such as plazas and local parks.
- Enhance spatial safety through proper urban design, lighting, and effective monitoring.
- Promote cultural and social events to strengthen social bonds.
- Introduce local culture through signage, symbols, and artworks in public spaces to reinforce Tabriz's cultural identity and deepen people's emotional connection to their place of residence

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BIM-based construction quality management: A bibliometric analysis

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Abstract. Building Information Modeling (BIM) has emerged as a transformative tool for the construction industry, offering significant potential to enhance design quality, minimize rework, and reduce conflicts. Integrating quality management within BIM applications ensures that construction processes are efficient, reliable, and aligned with project goals. Quality and its effective management are critical to the success of construction projects, ensuring efficiency, customer satisfaction, and compliance with standards. While "quality" spans various dimensions, including quality management, quality assurance, and quality improvement, its intersection with BIM applications has not been extensively explored. This study aims to conduct a bibliometric analysis of the existing literature to evaluate how BIM is integrated into construction quality management practices. The analysis identifies studies linking BIM with quality-related concepts, such as quality control, management, and continuous quality improvement. By examining publications indexed in the Web of Science (WoS) database from 1980 to 2025, this research aims to uncover patterns, trends, and key research gaps in the literature. Bibliometric tools like VOSviewer will facilitate the visualization of co-occurrence patterns, enabling a deeper understanding of thematic trends. 1,570 relevant articles were retrieved and analyzed, identifying 83 frequently used keywords grouped into six thematic clusters. Additionally, 25 highly cited and thematically relevant publications were reviewed in depth, revealing five dominant focus areas: BIM-based quality management systems, defect prevention and Zero-Defect Manufacturing (ZDM), organizational BIM maturity, process monitoring, and integrating emerging technologies. The findings indicate that BIM contributes to quality improvement across all project stages by enabling better collaboration, real-time monitoring, and process optimization. However, the literature remains largely conceptual, and future research should focus on empirical studies, comparative evaluations, and lifecycle-based assessments to establish measurable links between BIM implementation and quality performance outcomes.

Keywords: Building information modeling (BIM); Quality management; Construction industry; Bibliometric analysis.

1. Introduction

In recent years, Building Information Modeling (BIM) has emerged as a transformative technology within the construction industry, reshaping how projects are designed, managed, and executed. By enabling digital representations of buildings' physical and functional characteristics (Yan and Damian, 2008), BIM facilitates enhanced collaboration among stakeholders, reduces errors and omissions, and significantly improves decision-making processes (Azhar, 2011). One critical area where BIM has the potential to make a substantial impact is quality management, an essential component of successful construction project delivery.

Quality management in construction encompasses a broad range of practices to ensure that processes and outputs meet predefined standards, satisfy client requirements, and minimize rework and inefficiencies (Sun et al., 2017). These practices include quality planning, quality control, quality assurance, and continuous quality improvement. Despite the recognized importance of these concepts, integrating quality management principles into BIM applications has not been thoroughly investigated in the literature (Zhao, 2017). As the construction industry adopts digital tools and platforms, understanding how BIM can contribute to improving quality-related processes becomes increasingly vital. While several studies have explored the capabilities of BIM in areas such as cost estimation, scheduling, clash detection, and sustainability (Parsameh et al., 2023) fewer have directly addressed its role in supporting quality management frameworks. Given the complexity of construction projects and the multidimensional nature of quality, there is a growing need to assess how BIM is currently utilized in this context and identify gaps in the construction literature (Chen and Luo, 2014).

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This study aims to fill this gap by conducting a bibliometric analysis of scholarly publications related to BIM and quality management. By analyzing data from the Web of Science (WoS) database from 1980 to 2025, this research seeks to uncover patterns, trends, and emerging themes within the literature. Using bibliometric tools such as VOSviewer, the study will map out keyword co-occurrences and thematic clusters to provide a comprehensive overview of the current state of BIM-based quality management literature.

1.1 Quality in Construction and Its Relevance to BIM

Quality management in the construction sector is defined by its commitment to ensuring project deliverables meet client expectations, comply with regulatory standards, and are executed efficiently. It comprises four key elements: quality planning, assurance, control, and continuous improvement (Juran, 1992). Traditional practices in the construction industry have been predominantly reactive and paper-based, often leading to inefficiencies and overlooked quality issues. Recent research has highlighted the potential for integrating BIM into quality management processes for integrated and proactive quality management (Choi, Lee, and Kim, 2020). To understand BIM's contribution to quality in construction, it is essential first to define what "quality" entails. Sower and Fair (2005) noted that quality lacks a universal definition and is shaped by objective standards and user perception. Hoyer and Hoyer (2001) distinguish between two dimensions: one that aligns with technical specifications and another that emphasizes client satisfaction. This distinction is critical in BIM-enabled environments, where design outputs can be tailored through simulations to align with both performance metrics and user expectations.

Garvin (1984) outlines eight quality dimensions—performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality—that provide a structured approach to technically and perceptually assessing buildings. These dimensions gain practical relevance in BIM-integrated projects, where digital simulations can anticipate durability, energy use, and maintenance performance.

Juran's (1986) "Quality Trilogy"—comprising quality planning, control, and improvement—offers a useful lens for understanding how BIM supports quality at multiple stages.

- *Quality planning* involves setting project standards and ensuring alignment with client expectations. BIM enhances this by supporting early-phase scenario analysis, parametric design, and stakeholder engagement. Parasuraman et al.'s (1985) five quality gaps—understanding, design, process, operations, and perception—are also addressed through BIM's visual and collaborative features.
- *Quality control* is operationalized in BIM through real-time progress tracking, clash detection, and compliance verification, helping to detect deviations and correct them before costly errors arise. Juran (1986) highlighted that control is vital for maintaining output stability. BIM transforms this function from reactive inspections to anticipatory oversight.
- *Quality improvement* focuses on refining processes and outcomes. BIM supports two complementary strategies: income-oriented improvement through enhanced visualization and customization, and deficiency-oriented improvement by addressing root causes of inefficiency. Its simulation, data analytics, and feedback mechanisms enable a culture of continuous enhancement.

Golder et al. (2012) conceptualize quality as a dynamic process involving three interconnected stages: production, experience, and evaluation. BIM enhances each of these. During quality production, BIM facilitates stakeholder collaboration and simulation during early design phases. In quality experience, it ensures alignment with user needs via walkthroughs and performance modeling. In quality evaluation, it offers measurable post-occupancy data and benchmarks for assessing performance and guiding improvements.

2. Materials and Methods

This study aims to review the literature concerning the relationship between BIM and quality management through bibliometric methods. Analyzing publications indexed in the Web of Science database investigates how this relationship has been conceptualized, which dimensions and disciplines have been engaged, and what methodologies and research themes have been utilized. The study maps frequently used keywords and thematic clusters.

Bibliometric analysis utilizes various indicators and methods to evaluate the productivity, impact, and structural dynamics of scientific research, with productivity measured by publication volume across individuals, institutions, or countries, and impact assessed through citation counts, the h-index, and journal impact factors; structural analysis, on the other hand, employs techniques like citation analysis, co-citation, bibliographic coupling, co-authorship, and co-word analysis to reveal influential works, research clusters, collaboration networks, and thematic developments, offering a holistic view of knowledge generation (Zupic and Čater, 2015).

The reliability of such analysis depends heavily on high-quality bibliographic data from sources like the Web of Science, Scopus, and Dimensions, which provide detailed metadata. Tools such as VOSviewer, developed by Van Eck and Waltman (2010), enable the visualization of co-authorship, co-citation, and keyword networks.

In the context of this study, bibliometric analysis serves as a methodological foundation through which the integration of BIM into quality management practices within the construction industry is explored. Through a structured examination of academic publications, this approach aims to uncover:

- The evolution of research on BIM-related quality concepts (e.g., quality control, quality assurance, continuous improvement),
- Emerging research clusters and thematic trends,
- Potential gaps in the current literature.

Rather than relying solely on narrative literature review, bibliometric analysis provides an objective and reproducible method to evaluate a domain's current state of knowledge (Zupic and Čater, 2015). It facilitates the identification of underexplored areas in which BIM's role in quality management may be expanded, thereby contributing to forming a conceptual framework for future integration. The subsequent section presents the specifics of data collection, such as the selection of search terms, publication years, and database parameters. It outlines the practical implementation of the method adopted in this study.

3. Results and Discussion

In this research, the initial aim was to identify keywords related to the concept of quality to understand the relevant literature better. Thus, the goal was to access the term "quality" and other thematically related concepts. The search was conducted on the Web of Science database using filters for article type, English language, and inclusion in "SCI-Expanded" and "SSCI" indexes. Under these criteria, 2,481,042 records were retrieved. Using the refined tools of Web of Science—namely Web of Science Categories, Citation Topics Meso, Citation Topics Micro, and Research Areas—the dataset was narrowed down to 23,536 articles. When these were transferred to VOSviewer, 48,047 keywords were detected. Applying a minimum threshold of 35 occurrences, 271 keywords, and 6 clusters were identified. After eliminating unrelated terms, 38 keywords remained, which were grouped into five thematic categories: 1) Quality Management and Evaluation, 2) Project and Process Management, 3) Construction Sector and BIM-Related Terms, 4) Organizational Structures and Management, and 5) Optimization and Decision-Making Tools. These terms laid a foundation for evaluating the relationship between BIM and quality.

To further explore this relationship, a new search was conducted using the query TS=("building information modeling" OR "building information model" OR "BIM" OR "digital twin" OR "bim") AND TS=("quality" OR "tqm" OR "continuous improvement" OR "process improvement" OR "performance evaluation" OR "performance measurement" OR "six sigma" OR "taguchi method"). Applying the same filters (English, article type, SSCI/SCI-Expanded indexes), the search yielded 1,570 articles. (When the keyword "digital twin" was excluded, only 795 articles remained, thus justifying its inclusion.) In the conducted research, it has been revealed that the fields contributing to quality within the context of building information modeling (BIM) extend across a wide range of disciplines. these include management, computer vision & graphics, sustainability science, supply chain & logistics, knowledge engineering & representation, remote sensing, artificial intelligence & machine learning, statistical methods, optical electronics & engineering, design & manufacturing, software engineering, automation & control systems, and thermodynamics. This finding demonstrates the multidisciplinary nature of quality enhancement in BIM-based systems and emphasizes the importance of integrating technological, managerial, and analytical perspectives for effective implementation. The 1,570 retrieved articles were transferred to the VOSviewer tool. When the option "Create a map based on bibliographic data" was chosen, and the analysis type was set to "co-occurrence" and "author keywords," the program identified 5093 keywords that appeared at least once across the articles. These 5093 keywords may include repetitions. Therefore, to determine which keywords were used more frequently and to perform a density analysis, the minimum number of occurrences for a keyword was set to "10" using the "choose threshold" tab. By applying a minimum occurrence threshold of 10, the program filtered the initial 5093 keywords down to 83 with sufficient frequency for analysis. Fig. 1 illustrates the distribution and interrelations of these 83 terms. When examining the keywords of studies conducted on BIM and quality (Table 1), six thematic categories emerge: BIM, digital models and visualization, construction management and BIM application, quality management and assessment, digital technologies and industry 4.0, AI, simulation and data analysis, and sustainability.

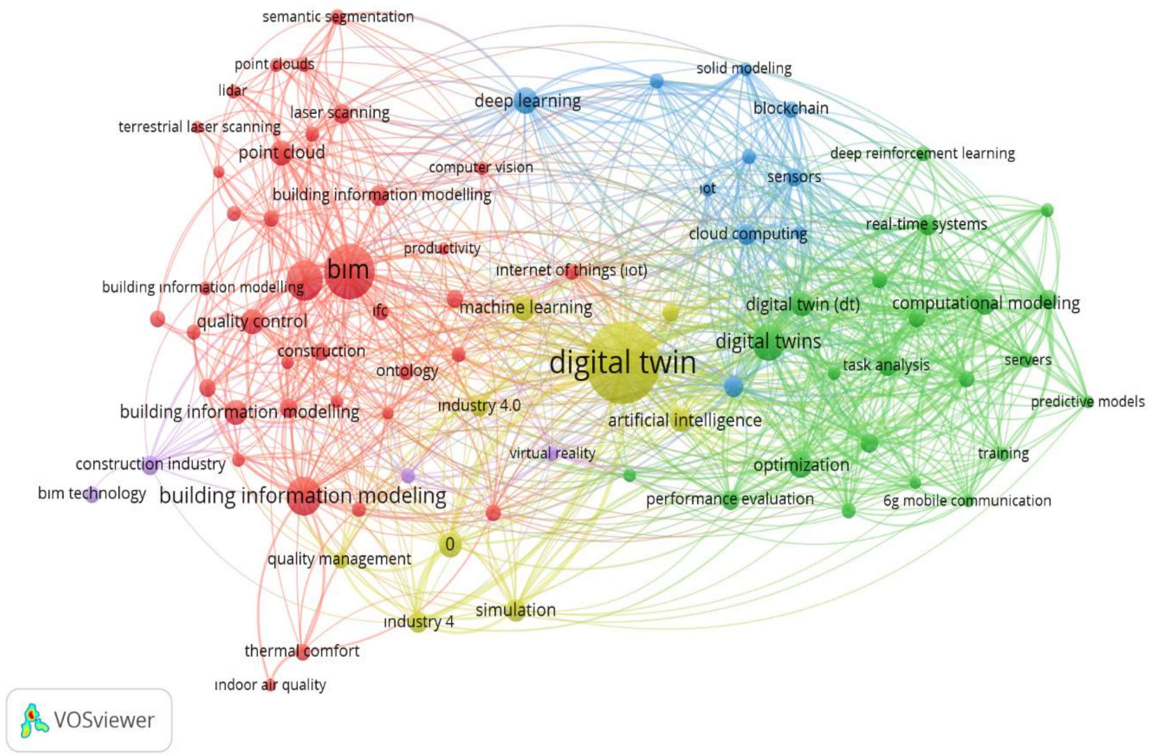

Fig. 1. Keyword Co-occurrence Map of 83 Terms (from 5093 keywords in 1,570 articles; min. occurrence: 10)

Table 1. Thematic Classification of Keywords in the Context of BIM and Quality Management

BIM, Digital Models & Visualization	Construction Management & BIM Application	Quality Management & Assessment	Digital Technologies & Industry 4.0	AI, Simulation & Data Analysis	Sustainability
digital twin	task analysis	quality control	cloud computing	deep learning	sustainability
building information modeling (bim)	construction industry	performance evaluation	internet of things(iot)	optimization	energy efficiency
point cloud	resource management	costs	real-time systems	machine learning	thermal comfort
laser scanning	facility management	quality of service	industry 4.0	computational modeling	indoor air quality
industry foundation classes (ifc)	construction management	quality management	servers industry 4.0	computer vision artificial intelligence	
3d reconstruction	automation	monitoring	edge computing	simulation	
three-dimensional displays	project management	quality assurance	sensors	data models	
augmented reality	resource allocation	quality	smart manufacturing	ontology	
building ınformation modeling	interoperability		blockchain	deep reinforcement learning	
virtual reality lidar	collaboration		internet of things (iot)	semantic segmentation	
point clouds	prefabrication		digitalization	predictive models	
scan-to-bım	productivity		mobile edge computing		
solid modeling			wireless communication		
terrestrial laser scanning			6G mobile communication		

As seen in Table 1, this classification highlights the multidimensional nature of the literature on the relationship between BIM and quality management, illustrating the technological, managerial, and analytical concepts that are most frequently addressed. It also provides researchers with a roadmap to explore in-depth analyses of datasets aligned with these thematic focuses.

According to the VOSviewer analysis, the concept of quality is frequently explored in conjunction with topics such as zero-defect manufacturing, quality management, modular construction, quality assurance, progress monitoring, automation, and point clouds, particularly within the domain of quality control. Fig. 2 visualizes the connections between "quality control" and 82 related keywords. Beyond its associations with BIM and digital twins, quality control exhibits thematic development through its links to point clouds, automation, modular construction, project management, progress monitoring, quality assurance, and zero-defect approaches. Similarly, Fig. 3 shows that quality assessment and its connection to BIM and digital twins evolve thematically through their ties to laser scanning and modular construction. Fig. 4 reveals that quality management, likewise associated with BIM and digital twins, is thematically linked to system dynamics, Industry 4.0, simulation, digitalization, sustainability, and zero-defect manufacturing.

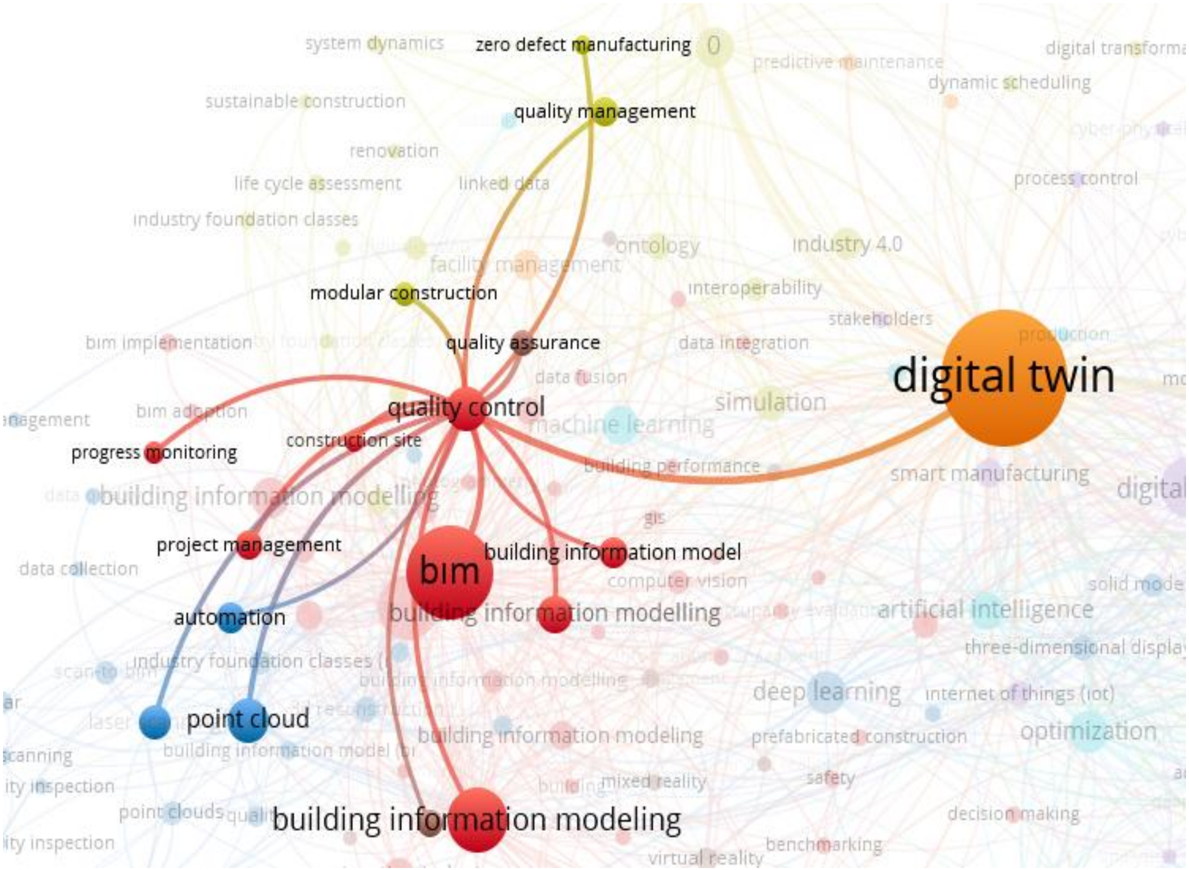

Fig. 2. Thematic Network of Keywords Associated with "*quality control*" Based on Co-occurrence Analysis

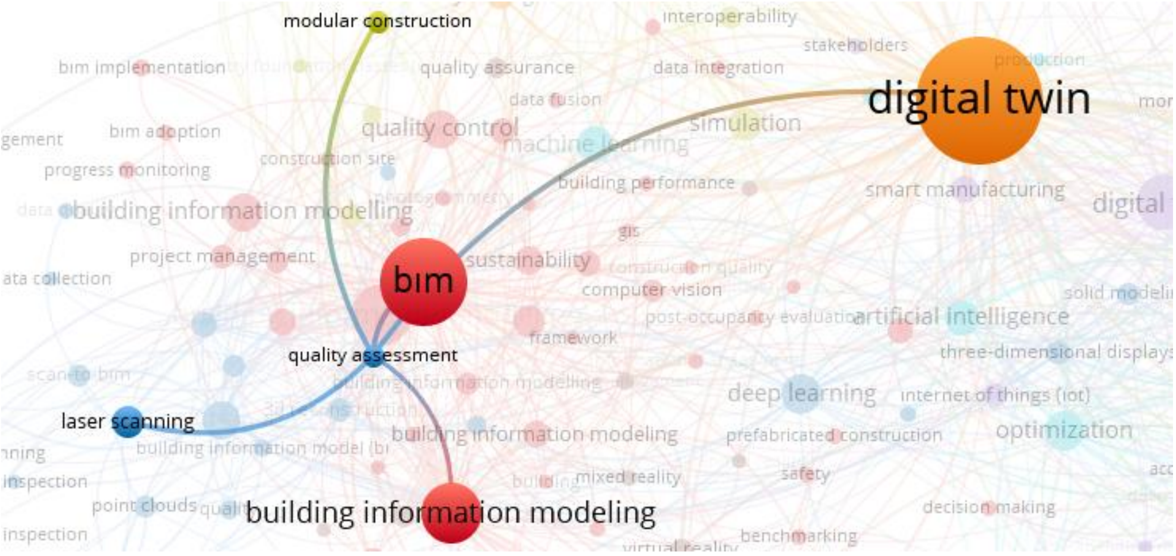

Fig. 3. Thematic Network of Keywords Associated with “*quality assessment*” Based on Co-occurrence Analysis

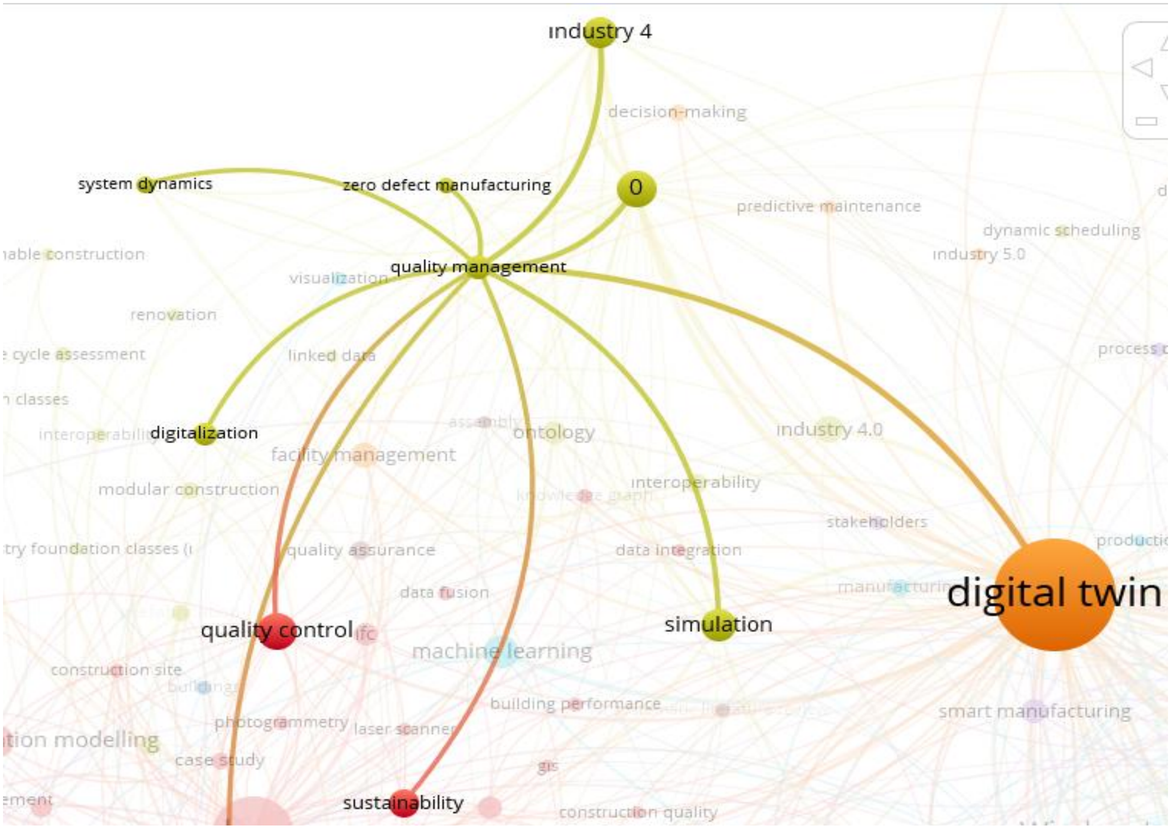

Fig. 4. Thematic Network of Keywords Associated with “*quality management*” Based on Co-occurrence Analysis

The thematic analysis of Fig.s 2, 3, and 4 reveals that quality-related concepts in the construction industry (namely *quality control*, *quality assessment*, and *quality management*) are strongly associated with digital technologies such as *BIM* and *digital twin*. A recurring theme across all three categories is integrating modular construction and pursuing *zero-defect* objectives, highlighting the industry's shift toward precision-driven and standardized production models. Moreover, while *quality control* is primarily linked to operational tools like *automation* and *point cloud*, *quality assessment* focuses on evaluation technologies such as *laser scanning*. In contrast, *quality management* demonstrates a broader strategic scope, aligning with system dynamics, Industry 4.0, and sustainability concepts. These findings suggest that quality in the construction sector is evolving through a multi-dimensional framework that combines real-time data, digital workflows, and long-term system optimization.

In this paper, a detailed review was also conducted on 25 thematically relevant papers selected from the top 200 most-cited among the 1,570 articles. Of these, 25 papers were chosen based on thematic relevance and reviewed in depth. The results are presented in Table 1, where the "Findings" column summarizes how each publication addresses the connection between BIM and quality.

Table 2. Summary of Key Findings from Selected BIM and Quality Management Studies

Source	Title	Findings
Psarommatis et al. (2022)	*"Zero-defect manufacturing: the approach for higher manufacturing sustainability in the era of industry 4.0: a position paper"*	This position paper establishes the conceptual foundation for Zero-Defect Manufacturing (ZDM) as a superior alternative to traditional quality improvement methods in the Industry 4.0 era. While it does not directly address BIM integration, it promotes a systemic shift in quality thinking that provides a valuable reference point for quality-driven BIM applications and smart construction environments.
Powell et al. (2022)	*"Advancing zero defect manufacturing: A state-of-the-art perspective and future research directions"*	The article positions Zero Defect Manufacturing as a transformative evolution of traditional quality management philosophies, aiming for systematic defect prevention and compensation across manufacturing and construction workflows. It highlights how moving towards a zero-waste, high-quality value chain strategy significantly strengthens sustainable and resilient quality assurance practices.
Yuan et al. (2022)	*"Digital twin-driven vehicular task offloading and IRS configuration in the Internet of Vehicles"*	While the article discusses digital twin and quality-related concerns such as latency and energy efficiency, it focuses entirely on vehicular networking in 6G environments, rather than construction or BIM-based quality improvement.
Wu et al. (2021)	*"On-site construction quality inspection using blockchain and smart contracts"*	This article proposes a blockchain-based framework for construction quality inspection, ensuring immutability, transparency, and automation in quality-related data management. Integrating smart contracts and IoT paves the way for real-time, secure, and reliable quality assurance, minimizing human error and enhancing accountability in on-site construction processes.
Psarommatis (2021)	*"A generic methodology and a digital twin for zero defect manufacturing (ZDM) performance mapping towards design for ZDM"*	The article proposes a forward-thinking ZDM methodology using digital twin simulations and Taguchi experiment design. This methodology enables real-time strategy mapping and performance optimization across manufacturing stages. Shifting from reactive to predictive quality control presents a strategic, data-driven framework for designing quality from the start of the production process.
Sheng et al. (2020)	*"Construction quality information management with blockchains"*	The article presents a blockchain-based framework that enables secure, transparent, and decentralized management of construction quality information. Improving traceability and accountability among stakeholders directly strengthens quality assurance processes and provides a digitally trustworthy infrastructure for managing nonconformance data in construction.
Franciosa et al. (2020)	*"Deep learning enhanced digital twin for Closed-Loop In-Process quality improvement"*	The article introduces a self-correcting, intelligent quality system by integrating a digital twin, deep learning, and CAE simulation to enable real-time defect prediction and mitigation. Its closed-loop framework supports continuous, automated, and in-process quality improvement, marking a shift from reactive to proactive quality control in manufacturing.
Maskuriy et al. (2019)	*"Industry 4.0 for the construction industry—how ready is the industry?"*	The article highlights how integrating BIM within Industry 4.0 cyber-physical systems enhances automation, optimizes data management, and improves construction lifecycle quality. Increasing accuracy, reducing errors, and promoting efficient workflows significantly contribute to continuous quality improvement and productivity gains in construction projects.

Table 2. continued.

Ma et al. (2018)	***“Construction quality management based on a collaborative system using BIM and indoor positioning”***	**The article enhances construction quality management by integrating BIM and indoor positioning technologies to enable more accurate, efficient, and collaborative inspection processes. Minimizing human errors and improving real-time stakeholder collaboration significantly support continuous quality assurance throughout the construction phase.**
Chen et al. (2018)	*“Construction automation: Research areas, industry concerns, and suggestions for advancement”*	Although the article does not propose a direct quality management model, it highlights how construction automation contributes to process consistency, error reduction, and improved productivity, all of which are fundamental quality aspects. It supports the strategic integration of automation into construction workflows to enhance process quality and overall performance.
Franz et al. (2017)	*“Impact of team integration and group cohesion on project delivery performance”*	The article demonstrates that higher team integration and cohesion significantly improve project quality, schedule, and cost outcomes. It highlights that quality management in construction is not only a matter of technical standards but also critically depends on organizational structure, communication efficiency, and collaborative practices, particularly those enabled by early contractor involvement and multidisciplinary BIM usage.
Gerrish et al. (2017)	*“BIM application to building energy performance visualization and management: Challenges and potential”*	The article explores how BIM can be utilized as a performance management tool by linking it with building management systems to visualize and optimize building operations. It improves quality by addressing data integration, behavioral adaptation, and technological alignment, enhancing operational building performance and overall quality outcomes.
Zadeh et al. (2017)	*“Information quality assessment for facility management”*	This article introduces a structured framework for evaluating the information quality of BIM models used in facility management. Aligning BIM content with FM user needs and operational demands provides a systematic and practical approach to ensuring model quality conformance, directly supporting long-term building performance and maintenance efficiency.
Smits et al. (2017)	*“Yield-to-BIM: impacts of BIM maturity on project performance”*	The article highlights that only strategic maturity in BIM implementation significantly predicts time, cost, and quality performance improvements. It emphasizes that BIM’s impact on quality depends on how strategically and intentionally it is embedded within organizational practices, not merely on its technical adoption.
Shalabi and Turkan (2017)	*“IFC BIM-based facility management approach to optimize data collection for corrective maintenance”*	The article demonstrates how leveraging BIM’s visualization and interoperability capabilities enhances the quality and efficiency of corrective maintenance data collection in facility management. Integrating maintenance alarms with related operational data in a 3D IFC-BIM environment improves response times, maintenance quality, and overall operational performance throughout the building lifecycle.
Giel and Issa (2016)	*“Framework for evaluating the BIM competencies of facility owners”*	The article provides a structured framework for building owners to evaluate and improve their BIM competencies, enhancing post-construction quality, data accuracy, and decision-making efficiency. Fostering lifecycle-oriented BIM strategies ensures quality is maintained and optimized beyond the design and construction phases.

Table 2. continued.

Oesterreich and Teuteberg (2016)	***"Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry"***	**The article investigates how the productivity—and quality-enhancing effects of digitisation and automation in manufacturing can be adapted to the construction industry. In this respect, it contributes to quality through a political and technological infrastructure perspective. Although it does not propose a direct quality model, it establishes a framework that promotes quality awareness.**
Abanda et al. (2015)	*"A critical analysis of Building Information Modelling systems used in construction projects"*	The article evaluates how different BIM systems impact information management, workflow efficiency, and project quality in the construction industry. Promoting more informed selection and strategic use of BIM software indirectly supports enhanced project outcomes and higher quality standards in construction projects.
Göçer et al. (2015)	*"Completing the missing link in building design process: Enhancing post-occupancy evaluation method for effective feedback for building performance"*	The article proposes integrating post-occupancy evaluation results into BIM models to create a continuous feedback loop for improving performance. Embedding operational insights into future designs directly supports long-term quality enhancement across the building's lifecycle, not just at the construction phase.
Wang et al. (2015)	*"Integrating BIM and LiDAR for real-time construction quality control"*	The article develops an integrated BIM and LiDAR-based system that enhances real-time defect detection and construction quality control. Enabling proactive quality management through real-time data processing significantly improves construction quality assurance efficiency, accuracy, and responsiveness.
Oh et al. (2015)	*"Integrated system for BIM-based collaborative design"*	The article enhances design phase quality by developing an integrated BIM-based system that addresses data loss, communication challenges, and workflow inefficiencies. Strengthening collaboration and ensuring data consistency across stakeholders significantly contributes to higher design quality and process efficiency in construction projects.
Al Hattab and Hamzeh (2015)	*"Using social network theory and simulation to compare traditional versus BIM–lean practice for design error management"*	The article introduces a novel framework for managing design errors by emphasizing team dynamics, early error identification, and communication patterns. Integrating BIM and lean methodologies supports a proactive and systemic approach to error prevention and quality improvement throughout the design phase.
Miettinen and Paavola (2014)	*"Beyond the BIM utopia: Approaches to the development and implementation of building information modeling"*	The article advocates for adopting local experimentation and organizational learning beyond normative standards in BIM implementation. This approach provides realistic and sustainable pathways for improving design and construction quality. While it does not propose a direct quality model, it establishes an intellectual foundation supporting organizational quality maturity development.
Chen and Luo (2014)	*"A BIM-based construction quality management model and its applications"*	The paper proposes a 4D BIM-based framework for integrated quality control during construction, linking design, organizational, and process data through a POP structure. By visualizing and managing quality requirements in real time, the study demonstrates how BIM can be an effective tool for proactive quality management beyond the design phase.
Park et al. (2013)	*"A framework for proactive construction defect management using BIM, augmented reality, and ontology-based data collection template"*	The article proposes an integrated system combining BIM, augmented reality, and ontology to enable proactive defect prevention in construction processes. It improves quality by enhancing data accuracy, defect traceability, and real-time field management.

This study conducts a thematic analysis of 25 high-impact, peer-reviewed articles (as presented in Table 2) investigating the intersection of Building Information Modeling (BIM) and quality management within the construction industry. Drawn from an initial pool of 200 highly cited publications, these selected studies offer critical insights into BIM's multifaceted contributions to quality enhancement across various dimensions of construction processes. The analysis identifies five overarching thematic categories emerging from the literature, as follows:

- *BIM-Based Quality Management Systems:*

Articles in this group focus on integrating BIM with quality workflows using technologies such as blockchain for data integrity, IFC-based data modeling, and BIM–Facility Management (FM) platforms. These systems help automate inspections, standardize documentation, and ensure traceability throughout the building lifecycle, supporting transparency and accountability.

- *Defect Prevention and Zero-Defect Manufacturing (ZDM):*

These studies align with Industry 4.0 paradigms, proposing proactive and predictive models that prevent quality issues rather than merely detect them. Digital twins, AI-enhanced real-time monitoring, and closed-loop defect control mechanisms are central to this theme, enabling early detection and response within construction or manufacturing processes.

- *Organizational BIM Maturity and Strategic Integration:*

Several articles emphasize that the success of BIM in quality enhancement is highly dependent on strategic maturity, institutional readiness, and integrated workflows. Without organizational alignment, BIM adoption may yield only partial benefits. This theme underscores the need for investment in training, culture change, and long-term digital strategies.

- *Process Monitoring, Feedback, and Lifecycle Evaluation:*

This cluster includes real-time progress monitoring, performance evaluation, and post-occupancy feedback studies. BIM manages construction and gathers operational data that informs future design and operation decisions, promoting a continuous improvement cycle.

- *Emerging Digital Technologies and Quality Enhancement:*

The final group explores advanced digital integrations including blockchain, IoT, AR, and AI. These technologies provide enhanced visibility, data security, and automation to the quality process, making quality management more responsive, accurate, and decentralized.

An in-depth analysis of the selected 25 articles reveals a diverse application of BIM tools in quality management. The most frequently employed features include 4D BIM, IFC-based modeling, BIM–FM integration, and digital twin systems. Additionally, advanced technologies such as augmented reality (AR), blockchain-enabled quality tracking, indoor positioning systems, and AI-driven analytical tools are increasingly utilized in quality control processes. These tools facilitate faster information flow, reduce defect rates, and enhance inspection traceability. As for quality indicators, the reviewed studies commonly emphasize traditional performance criteria such as cost control, schedule adherence, and defect/error rates. However, digital transformation-oriented metrics such as data accuracy, rework reduction, user feedback integration, preventive maintenance efficiency, and automation levels in quality assurance are also prevalent. In terms of methodology, the studies predominantly rely on case study analyses and conceptual framework proposals, while also incorporating simulation models, prototype system designs, systematic literature reviews, surveys, and the Delphi method. This variety highlights the multidimensional nature of BIM in addressing quality management both theoretically and practically.

4. Conclusions

To investigate how BIM is integrated into quality management practices, a bibliometric analysis was conducted using the Web of Science (WoS) database in this study. The findings indicate that the relationship between Building Information Modeling (BIM) and quality management in the construction industry has evolved through a multidimensional framework that integrates technological, managerial, and analytical perspectives. The bibliometric analysis of 1,570 articles identified 83 frequently used keywords, categorized into six thematic clusters, reflecting the key areas where BIM intersects with quality concepts. *Quality control*, *quality assessment*, and *quality management* are thematically connected with concepts such as BIM, digital twin, modular construction, automation, point cloud, laser scanning, simulation, Industry 4.0, and sustainability. A detailed review of 25 highly cited and thematically relevant studies revealed five dominant themes: (1) BIM-based quality management systems, (2) defect prevention and Zero-Defect Manufacturing (ZDM), (3) organizational BIM maturity and strategic integration, (4) process monitoring and lifecycle evaluation, and (5) emerging digital technologies in quality enhancement. These studies showed that while BIM tools like 4D modeling, IFC-based data exchange, and digital twins improve efficiency and quality oversight, the success of BIM in quality outcomes also depends on strategic planning, organizational culture, and integration with advanced technologies such as blockchain, IoT, and AI. The reviewed 25 studies mostly emphasized cost, time, and defect reduction improvements, highlighting new digital performance indicators such as data accuracy, process automation, and post-occupancy feedback integration.

BIM's role in quality should not be viewed solely as a technological innovation but as a comprehensive digital transformation strategy encompassing data management, organizational change, and capacity-building initiatives, such as training programs. Although the reviewed studies provide valuable conceptual frameworks and proof-of-concept applications, there is a noticeable lack of empirical evidence that links BIM usage to quantifiable quality outcomes. The majority of the existing contributions are either exploratory or theoretical in nature. Future research should focus on establishing empirical correlations between BIM implementation and specific quality indicators, such as cost reductions and defect rates. Additionally, there is a need for comparative studies that examine the impact of BIM across various project types, countries, and organizational settings. Extending quality management research beyond the construction phase to include operational, maintenance, and sustainability aspects within the BIM ecosystem will further enhance the holistic understanding of BIM's influence on quality across the project lifecycle.

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Non-formal learning environments and their importance in architectural education

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Abstract. Non-formal learning refers to the processes through which individuals acquire knowledge via experiential, social, or everyday practices that occur outside of a structured curriculum or formal instructional setting. Particularly in the context of higher education, it enables individuals to enhance their personal competencies, strengthen critical thinking skills, and improve their capacity for creative problem-solving. In disciplines that encompass both technical and artistic dimensions, such as architectural education, classroom-based formal education alone is often insufficient. Therefore, non-formal learning environments serve as a vital complement to formal education by providing flexible, participatory alternatives that support individual development. This study focuses on non-formal learning within architectural education. As a literature-based investigation, it explores the limitations experienced by architecture students engaged in formal learning processes and examines the contributions that non-formal learning environments offer. Within this context, the concepts of formal, non-formal, and informal learning are defined, and the specific contributions of non-formal learning to architectural education are discussed.

Keywords: Architectural education; Learning environments; Formal learning; Non-formal learning; Informal learning.

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1. Introduction

While vocational education processes provide individuals with certain knowledge and skills, the deepening of expertise and competencies acquired through these processes depends on personal experience and the assimilation of knowledge across diverse contexts. Although many of these requirements are addressed during traditional formal education, it is crucial for individuals to engage with experience-based learning opportunities offered by non-formal environments to further develop their expertise. In particular, individuals seeking to gain competencies in diverse domains should actively participate in less formal, flexible, and practice-oriented learning processes alongside structured educational experiences (Johnson & Majewska, 2024). Considering the rapidly evolving demands for knowledge and skills in today's world, integrating these two structures in a complementary manner presents important opportunities for developing more adaptable and learner-centered educational models. In this regard, the supplementary role of non-formal learning environments in supporting formal education warrants further investigation.

In today's educational landscape, where pedagogical paradigms are becoming increasingly flexible and multidimensional, the transformation of vocational education has become inevitable. Architectural education, in particular—a field that is both creative and practice-oriented—is significantly affected by this shift. It aims to foster students' active engagement in conceptualization, design, critical thinking, and construction processes, while simultaneously enhancing individual expression and representational abilities (UIA, 2023). However, acquiring these skills solely through formal, classroom-based instruction is insufficient due to the inherent nature of architectural education. As a discipline, architecture necessitates the continuous monitoring of technological innovations, sociocultural transformations, and environmental dynamics. Consequently, a learning approach confined strictly to the parameters of a structured curriculum cannot fully accommodate the dynamic demands of the profession or lifelong learning (Cantürk Akyıldız & Özgüven, 2024).

Against this backdrop, the present study focuses on the role of non-formal learning environments within architectural education. This literature-based research examines the limitations faced by architecture students engaged in formal learning processes and explores the ways in which non-formal environments address these challenges. To this end, the study first defines formal, non-formal, and informal learning types, outlining their similarities and differences. It then identifies the shortcomings of formal education within architectural pedagogy

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and highlights the potential of non-formal environments as a supportive mechanism for addressing these gaps. The analysis explores how students incorporate non-formal learning environments into their broader learning ecosystems and how such environments help them to navigate and overcome the limitations of formal instruction. Ultimately, the study aims to illuminate the complementary relationship between the rigid structure of formal education and the flexibility provided by non-formal learning environments.

A further aim of the study is to clarify the conceptual ambiguities identified in the existing literature. In Turkiye, particularly in studies focused on architectural education, notable inconsistencies exist in the terminology used to define learning processes. It is frequently observed that all learning outside of formal education is broadly labeled as “informal learning environments” (Yılmaz, 2009; İmamoğlu, 2019; Sarman, 2021; Özdemir Gökmen, 2023). The significance of this research lies in its effort to provide a clearer conceptual framework for distinguishing non-formal learning in the context of architectural education. By critically analyzing and differentiating these learning types—often conflated under generalized terms—the study contributes a more nuanced theoretical perspective to the field.

2. Types of Learning

Education is a multidimensional process that supports the cognitive, affective, and social development of individuals. In the literature of educational sciences, learning is commonly categorized under three main headings: Formal Learning, Non-Formal Learning, and Informal Learning (OECD, 2010). These learning types differ in terms of the learner’s level of participation, the context in which learning occurs, and the modes of assessment. However, they are often regarded as complementary components within a broader educational ecosystem (Rogers, 2014). Therefore, in order to define non-formal learning meaningfully, it is essential to explore its relationship with both formal and informal learning.

Formal learning occurs within structured and institutionalized environments, follows a defined curriculum, and typically results in a diploma or certificate (UNESCO, 2012). A formal curriculum represents a written program organized around specific content areas, topics, and learning resources, assessed through theoretical or practical examinations (Leask, 2009, p. 207). In this model, the roles of the instructor and the learner are clearly defined, and the content, learning objectives, and assessment criteria are predetermined. Every phase of the learning process is planned and intentional, and student participation is regulated by certain obligations.

Through its structured framework, formal learning contributes to standardizing knowledge and skills, thereby promoting equality and accessibility in education. It enhances social mobility and provides disadvantaged individuals with opportunities for upward movement in society. Additionally, it plays a crucial role in preserving and transmitting society’s collective knowledge—such as history, science, and culture—across generations. Formal education also ensures the traceability and accountability of learning through systematic evaluation processes (Johnson & Majewska, 2022). Nevertheless, despite these strengths, formal learning can bring about various structural and functional limitations that may negatively impact students’ academic performance and learning motivation. Hence, integrating formal education with other learning types is essential for a more effective and holistic learning experience.

Informal learning, in contrast, refers to lifelong learning processes through which individuals acquire knowledge, skills, attitudes, and insights from everyday experiences and environmental interactions (Coombs & Ahmed, 1974). This form of learning is unstructured and typically lacks a defined curriculum, teaching plan, or formal assessment (OECD, 2010). It occurs spontaneously and naturally, with outcomes that are not predetermined. Instructors are often not professional educators, but rather individuals such as parents, grandparents, peers, or experienced community members. Informal learning extends beyond institutional settings and may take place at home, in workplaces, community centers, or during leisure activities. Despite the absence of formal organization, it significantly contributes to cognitive, social, and emotional development. Notably, informal learning represents a substantial portion of lifelong learning and remains impactful even among individuals with advanced formal education (Coombs & Ahmed, 1974; Johnson & Majewska, 2022).

Non-formal learning encompasses structured, planned, and organized learning processes that occur outside the formal education system and do not lead to an official diploma or academic degree. While it is goal-oriented and systematic in nature, participation is voluntary and often aims to enhance the learner’s social, cultural, or professional development.

In non-formal learning, learners typically steer the process based on their interests and needs, while the instructor serves as a facilitator or guide. Effective peer communication and collaboration are central to this approach, which fosters individual motivation and strengthens social cohesion (Özsoy et al., 2017). Examples of non-formal learning environments include online or in-person courses, workshops, summer schools, volunteer projects, and seminars (Harris & Wihak, 2018). Furthermore, the flexible structure of non-formal learning supports learner autonomy and contributes to the cultivation of a lifelong learning culture by enabling individuals to tailor their educational pathways.

Formal, non-formal, and informal learning differ in terms of structure, methodology, and objectives. However, it is not always possible to draw strict boundaries between these forms, as they often demonstrate overlapping features and complement one another. Table 1 provides a comparative overview of the key characteristics of these three learning types, highlighting both their similarities and distinctions.

Table 1. Comparing structural and formal characteristics of learning types (Johnson & Majewska, 2022).

Features	Formal Learning	Non-Formal Learning	Informal Learning
Structure	Structured (includes linear objectives)	Can be structured	Not structured
How Learning is Incentivized	Promoted through direct teaching behaviors	Promoted through indirect teaching behaviors	Learning is encouraged in the natural process
Defining Learning	Defined by the trainer and the learner	Defined in line with the learner's purpose	Learning is shaped by the needs of the learner
Motivation	Extrinsic motivation is dominant	Intrinsic motivation is an important element	Intrinsic motivation is naturally part of the process
Realization Location	Takes place in educational institutions	Can take place inside or outside educational institutions	Can take place in any setting (home, work, community)
Participation Status	Mandatory	Can be voluntary	It is based on volunteerism
Measurement and Evaluation	Defined and measured through competencies	Identifiable or measurable through competencies	Outcomes of learning are not always measured or assessed by qualifications
Cognitive Dimension	High emphasis on cognitive knowledge	Includes cognitive, affective and social elements	Cognitive, affective and social development is supported in the natural process
Curriculum	It is written down and mandatory	Can be written down	No written curriculum
Learning Process Aspect	Top-down: transferring specific knowledge and skills	Bottom-up: focused on the needs of the learner	It develops completely spontaneously according to the needs of the individual
Relationship with Curriculum	Follows the official curriculum	Can complement the formal curriculum	Often not directly linked to the formal curriculum
Relationship with Socialization	Linked to socialization	May or may not be linked to socialization	Often strongly linked to socialization

An examination of the key characteristics compared in the table reveals that formal, non-formal, and informal learning styles possess distinct structural features; however, these differences do not establish rigid boundaries. Informal learning occurs spontaneously at every stage of the learning process, as it is shaped by unplanned and unstructured experiences that naturally unfold throughout an individual's life. Therefore, informal learning is not the opposite of formal education but rather a natural complement to it, often interwoven with formal structures. Conversely, non-formal learning occupies an intermediate space between formal and informal learning styles. It combines a degree of structure and intentionality with voluntary participation and flexibility, thus forming a common ground between the two extremes (Fig. 1). In this sense, formal, informal, and non-formal learning exhibit a complementary and integrative relationship.

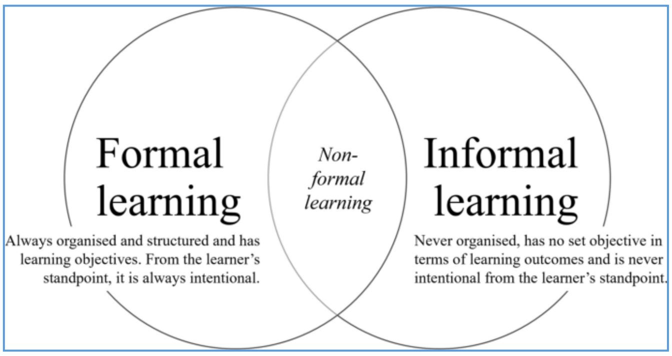

Fig. 1. The interrelatedness of learning styles (Johnson & Majewska, 2024).

3. Limitations of formal learning and its relationship with non-formal Learning

Formal learning is a fundamental model that enables individuals to develop knowledge and skills through a systematic and structured process, thereby supporting equality, accessibility, and quality in education. However, its focus on a predetermined structure and standardized objectives can, in some cases, hinder the ability to fully address students' diverse learning needs and individual development processes. In this context, the literature increasingly supports the view that formal learning should be complemented by other modes of learning.

To begin with, the grade-centered assessment systems inherent in formal education can negatively affect students' motivation and attitudes toward learning, and performance-driven approaches may at times limit the depth of learning. One of the most significant psychological factors that creates pressure on academic performance is grade anxiety. This form of anxiety, which intensifies during exam periods, may prevent students from reaching their full potential (Von der Embse et al., 2018). By fostering performance-based stress, such assessment systems shift the focus from intrinsic to extrinsic motivation. Consequently, particularly in programs heavily reliant on exam success, students tend to experience mental fatigue, avoid deep learning, and adopt surface-level knowledge acquisition habits.

Additionally, delays in curriculum updates and the inability of academic content to keep pace with sectoral changes challenge students' adaptation to evolving knowledge and skill requirements. In an era marked by rapid technological and methodological transformation, the slow pace of curricular revision in higher education institutions can lead to decreased student interest, lower motivation, and diminished practical competence. Moreover, it weakens the alignment between academic content and real-world needs (Alsadoon, 2020).

The lack of technological infrastructure and limited access to digital resources also constitute significant barriers to contemporary learning experiences (Assefa, 2025). Particularly in university settings, access to online learning materials, audiovisual content, and digitally supported practical applications is contingent on robust technological infrastructure. When lacking, students face challenges in accessing educational content, thereby diminishing the effectiveness of interactive learning processes.

Furthermore, the excessive volume of course content presented within formal curricula can act as a suppressive factor for learning (Kaya & Erdem, 2021). Dense academic schedules limit students' ability to engage in self-directed learning and hinder the development of high-order cognitive skills such as critical thinking and independent research. As a result, students are driven away from creative thinking and pushed toward an exam-oriented learning style.

Another limitation of formal learning is its lack of interdisciplinarity. Interdisciplinary learning environments encourage students to transcend the boundaries of their primary fields, embrace contributions from other disciplines, and critically analyze potential conflicts among diverse approaches—fostering deeper intellectual engagement. In this regard, interaction-based, interdisciplinary education plays a critical role in addressing today's complex and multifaceted knowledge demands (Corbacho et al., 2021). However, traditional formal education models often remain confined within single disciplinary frameworks, offering limited opportunities to cultivate a holistic perspective.

Finally, attendance policies enforced in higher education institutions can also negatively affect students' learning experiences. Although intended to encourage class participation, such policies may overlook individual learning styles and flexible working arrangements (Zhu et al., 2019). For students capable of managing their own learning, conducting research-based studies, or balancing academic life with professional commitments, rigid attendance requirements may restrict motivation and academic autonomy.

In contrast to all these limitations, non-formal learning environments offer flexible, participatory, and experience-based structures that play an important complementary role. With voluntary participation, personalized content tailored to individual interests, accessible technological tools, and a pressure-free approach that fosters intrinsic motivation, non-formal learning provides alternative and effective opportunities where formal education falls short. In addition, through online modules, hybrid activities, and self-paced planning, non-formal settings can alleviate constraints such as attendance requirements. Furthermore, workshops, summer schools, and competitions that bring together participants from various disciplines contribute to interdisciplinary interaction. In this way, students can engage in a more holistic learning process that prioritizes creativity, problem-solving, communication, collaboration, and personal development rather than focusing solely on academic achievement (Fig. 2).

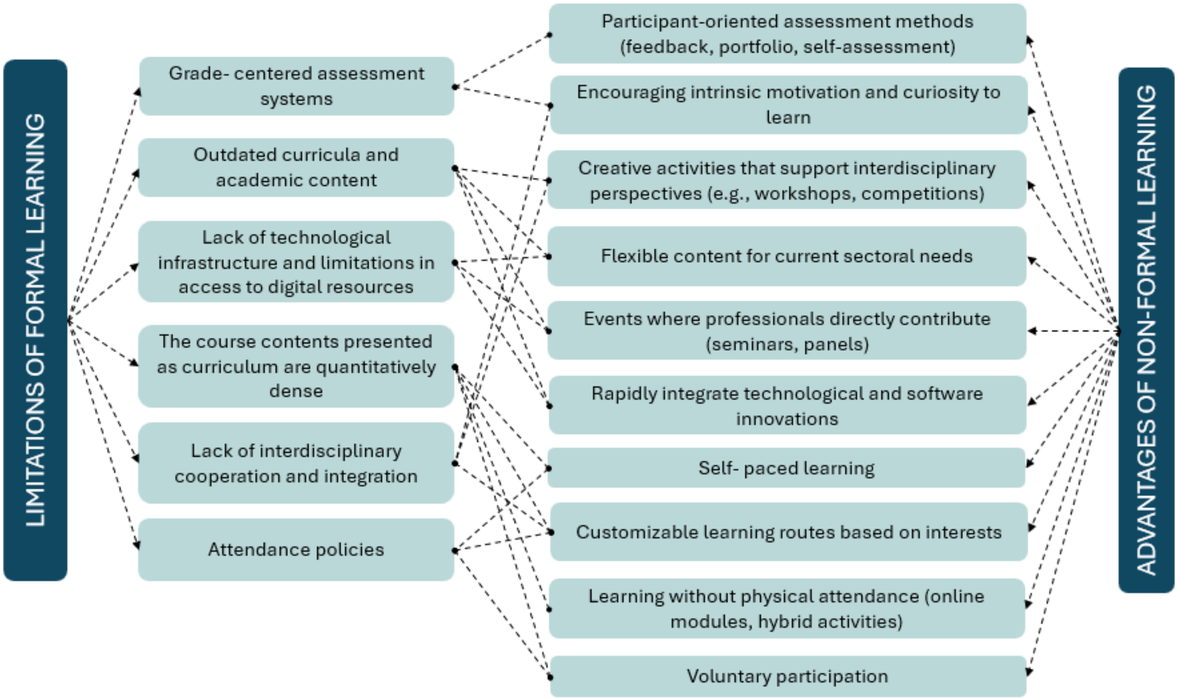

Fig. 2. A comparative illustration of the advantages of non-formal learning in response to the limitations of formal learning

4. Architectural education and non-formal learning

In Turkiye, the Turkish Higher Education Qualifications Framework (TYYÇ), established by the Council of Higher Education (YÖK), defines the knowledge, skills, and competencies that individuals are expected to acquire at all levels of vocational programs, including architecture. According to this framework, architectural education should equip future architects not only with theoretical and factual knowledge related to the field but also with cognitive and practical skills. Additionally, architecture students are expected to develop competencies in independent work and responsibility, learning ability, communication and social interaction, as well as professional ethics and behavioral awareness (URL 1, 2025). Among these, the learning competency category includes the following objectives: "Acts with future orientation, possesses the motivation and learning skills required for personal and professional development, identifies learning needs, makes and implements plans accordingly" and "Acts with an awareness of lifelong learning." Thus, the TYYÇ suggests that learning should not be limited to formal education and that future architects are expected to be capable of complementing their formal learning through other modes of education.

From Vitruvius to the present, architecture has been defined as a multidimensional design discipline that integrates functionality, durability, and aesthetic values while organizing spaces in line with human needs, blending artistic, technical, and social processes in a holistic manner. Since antiquity, it has been widely accepted that an architect is not merely a builder, but a well-rounded intellectual with deep knowledge across multiple domains. An architect is expected to demonstrate competence in fields such as geometry, mathematics, history, philosophy, music, medicine, and astronomy; combine aesthetic sensitivity with technical knowledge; and produce structures that adhere to natural laws while serving human needs. Moreover, they are expected to possess the ability to translate theoretical knowledge into practice, supported by an artistic perspective (Vitruvius, 1993: 4–5). In this sense, the definition of design proposed by Bremner and Rodgers (2013)—as a concept nourished by cultural, professional, economic, and commercial disciplines—can also be adapted to the field of architecture (Fig. 3). Accordingly, architecture maintains direct and indirect connections with numerous fields, ranging from social sciences such as art, history, archaeology, anthropology, psychology, and sociology, to disciplines such as civil engineering and biology (Şensoy & Yamaçlı, 2015). This multifaceted nature of architecture compels architectural education to evolve into a dynamic process that is responsive to diverse problems and continuously adapts to technological advancements.

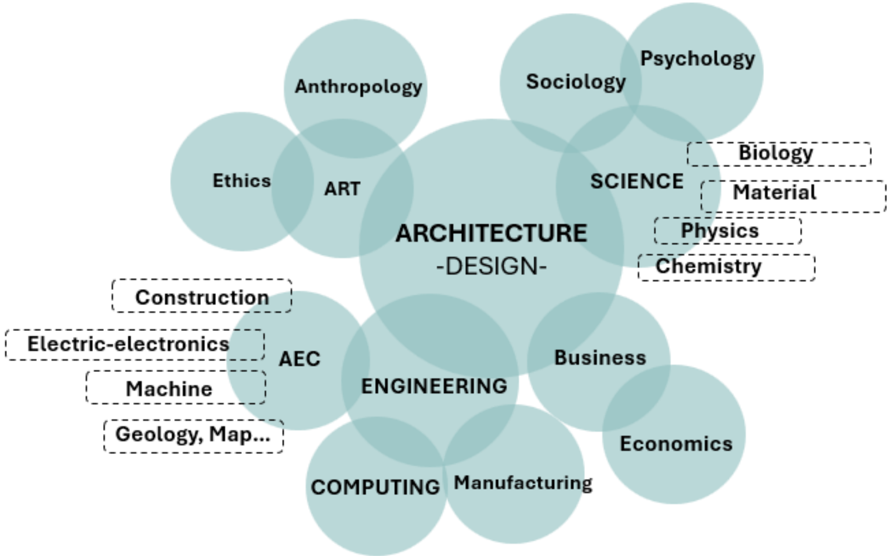

Fig. 3. An architectural adaptation of Bremner and Rodgers' (2013) design scheme

As a discipline situated at the intersection of multiple fields, architecture offers a formal education framework that combines theory and practice within a comprehensive curriculum. However, it is difficult for architecture students to acquire all the knowledge, skills, and competencies expected of them solely within the limited scope of a four-year undergraduate program. In this regard, it is well recognized that students voluntarily support their education and contribute to their professional development through non-formal learning environments. Particularly in light of ongoing technological advancements, there is increasing debate about the extent to which architectural education programs can adequately respond to the evolving demands and conditions of the contemporary world. As such, architecture education is currently undergoing one of its most extensive and rapid periods of transformation (Sancar Özyavuz, 2012). Consequently, there is a growing need to revise and adapt the overall curricular structure of architectural education (Soliman et al., 2019). Nevertheless, the limitations of formal education also manifest in this process. It is highly challenging for curricula to keep pace with the rapid flow of technological, hardware, and software developments. Moreover, expecting the curriculum to include diverse course content tailored to the interests and curiosities of each individual student over a four-year program is simply unrealistic. At this point, the importance of non-formal learning environments in architectural education becomes evident.

In contrast to formal education, which is tied to a specific curriculum and primarily centered around theoretical instruction, non-formal education not only focuses on the development of vocational skills but also fosters attitudes and competencies critical for future career success (Dib, 1988). Research shows that non-formal education can more effectively respond to students' individual needs and their expectations for better understanding themselves and their environments. Accordingly, non-formal learning presents a flexible, interest- and needs-based educational approach capable of rapidly adapting to the changing conditions of individuals and society (Todaro, 1995).

Non-formal learning in architecture encompasses a broad range of extracurricular activities that encourage individuals to participate in out-of-school experiences aimed at enhancing their skills and competencies. Such activities include workshops, conferences, design marathons, summer schools, design competitions, and exhibitions, each offering diverse formats and methods (Bratuškins et al., 2018, p. 46). Workshops, in particular, have become indispensable within architectural non-formal learning environments by providing a platform for discussing design practices, exchanging ideas, and fostering collaboration. Conferences and seminars enable students to interact with professionals and academics, keep up with current developments in the field, and engage in critical discourse (Fig. 4). These collaborative and informal settings also help students develop teamwork and communication skills, and facilitate networking by engaging with various stakeholders (Cantürk Akyildiz & Özgüven, 2024).

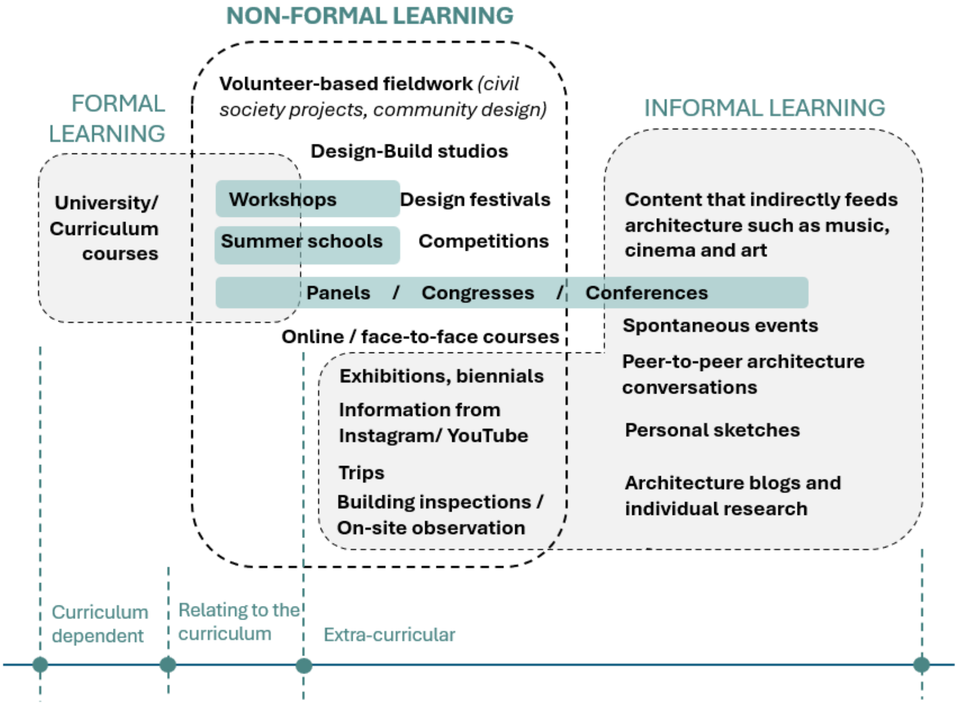

Fig. 4. Formal-non-formal-informal interaction in architectural education (Adapted from Özdemir Gökmen, 2023).

5. Conclusion

Traditional academic structures have long positioned formal learning as the central reference framework for education, emphasizing school-based knowledge transmission. However, with the rise of digitalization and socially interactive learning tools, profound transformations have occurred in how individuals access, process, and produce knowledge. This shift has fostered a new learning ecosystem that extends beyond formal education, elevating the significance of non-formal and informal learning modalities (Harris & Wihak, 2018). Particularly today, technological advancements have blurred the boundaries between formal and non-formal learning, leading to a continuous evolution of learning ecologies (Nygren et al., 2019).

Within this framework, non-formal learning emerges as an important alternative approach that complements the structured and institutional framework of formal education by offering flexible and individualized learning opportunities. Non-formal learning environments—through voluntary participation, adaptable content tailored to individual interests, experiential learning activities, and socially interactive formats—hold the potential to diversify and enrich educational processes.

It is well documented that learning experiences directly linked to students' areas of interest and real-life problems significantly increase their motivation and engagement (Afeldt et al., 2018). When knowledge is acquired in direct connection with practical contexts, learning becomes not only more lasting but also more meaningful (Badger, 2021). Non-formal learning environments empower individuals to focus on areas they enjoy, thereby strengthening intrinsic motivation and enabling them to develop flexible thinking skills by forming connections across various contexts (Johnson & Majewska, 2022).

Non-formal activities such as site visits, workshops, summer schools, and volunteer projects have been shown to generate holistic cognitive, affective, and social impacts on learners (Badger, 2021). On the emotional level, they increase students' interest and engagement; on the cognitive level, they enhance access to information and support long-term memory formation; and on the social level, they foster the development of skills such as communication, collaboration, leadership, and social responsibility (Frappart & Frède, 2016). In particular, non-formal learning environments play a critical role in the development of higher-order cognitive skills such as critical thinking, problem-solving, comparative analysis, and evaluating multiple perspectives (Badger, 2021). This dynamic structure enables students to approach learning not merely as an academic obligation but as an opportunity for personal growth and lifelong learning, allowing for more active, engaged, and meaningful participation in learning processes.

In conclusion, while the systematic structure and academic standards provided by formal learning continue to serve as the foundation of educational systems, non-formal learning—with its responsiveness to individual differences, flexible design, and experiential focus—assumes a complementary and enriching role. Therefore, a balanced and integrated application of both approaches is essential to support holistic student development and strengthen lifelong learning competencies within contemporary higher education.

This study, which highlights the importance of non-formal learning in architectural education, clarifies the structural distinctions among formal, non-formal, and informal learning modalities. Accordingly, it addresses the conceptual ambiguity in the architectural literature, where out-of-school learning processes are often grouped under the umbrella term "informal learning." The analysis demonstrates that informal learning corresponds to unstructured, spontaneous, and unplanned processes, whereas non-formal learning comprises activities that are organized with specific goals and structures, relying on voluntary participation. Consequently, applications such as workshops, seminars, summer schools, design-build studios, architectural design competitions, and online education modules—due to their planned and organized nature—should be categorized under non-formal learning environments. By clarifying these distinctions, the study not only emphasizes the significance of diverse learning types in architectural education but also contributes a theoretical framework to resolve the conceptual confusion in the literature.

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Multidisciplinary sustainability model in post-disaster housing recovery: user-oriented and energy-efficient strategies

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Abstract. The increasing frequency and complexity of disasters have posed significant challenges across environmental, economic, social, and cultural domains, bringing the sustainability of post-disaster housing to the forefront of policy discussions and recovery efforts. In response to these challenges, this study introduces a multidisciplinary model that integrates energy-efficient and user-oriented strategies, aligned with the principles of sustainable development and relevant goals. To develop this model, a systematic literature review of 59 academic sources was conducted using the PRISMA framework, enabling the identification and synthesis of key strategies. The review is guided by two central questions: (1) What are the key energy-efficient strategies that reduce environmental impact and minimize energy consumption? Moreover, (2) What user-oriented design strategies enhance the adaptability and livability of post-disaster housing to meet the diverse needs of affected populations?. The findings are thematically categorized into eleven strategic themes: five related to energy efficiency and six to user-oriented approaches. Energy-efficient strategies encompass passive design, improved thermal comfort and reduced energy consumption, the utilization of both traditional and advanced materials, life cycle assessment (LCA), and cost-effective design and economic feasibility. In parallel, user-oriented strategies emphasize human rights, psychological well-being and social cohesion, socio-cultural resilience and community-based practices, technology and innovative design, evaluation and optimization frameworks, and governance, strategic planning, and community participation. These strategies provide a comprehensive foundation for developing context-sensitive, inclusive, and sustainable solutions for post-disaster housing recovery.

Keywords: Post-disaster recovery; Temporary housing; Sustainability model; User-oriented; Energy-efficient

1. Introduction

Disasters, whether natural, human-made, or hybrid, threaten lives and communities. Natural disasters, such as meteorological, geophysical, hydrological, biological, and climatological events, and human-made disasters, resulting from human activity, negligence, or conflict, can severely impact the built environment and lead to sociopolitical unrest, technological failures and infrastructure collapse (Galderisi & Ceudech, 2013; Shaluf, 2007; The & Khan, 2021). In recent decades, disasters' growing frequency and complexity have intensified post-disaster management challenges across environmental, economic, political, social, and cultural dimensions (Shaw, 2014; Safapour et al., 2021). Yi et al. (2020) identify the core phases of post-disaster management as "relief, reconstruction, rehabilitation, and recovery" (p. 1), which together encompass physical reconstruction, socioeconomic and socio-cultural rehabilitation, and policy-driven strategies to strengthen resilience against future hazards (Berke et al., 1993; Peacock et al., 2018; Mukherji, 2014). Housing recovery has emerged as a critical priority (Berke & Campanella, 2006). As one of the most vulnerable components in disasters, housing serves as a physical shelter and a foundation for social life (Tas et al., 2007; Félix et al., 2013). Its destruction displaces populations, fragments communities, and undermines overall well-being. Post-disaster housing recovery requires balancing immediate and long-term needs by integrating emergency shelter, transitional housing, and permanent reconstruction efforts that not only provide safe, adequate homes but also reduce future vulnerabilities and foster community resilience (Johnson & Olshansky, 2016; Peacock et al., 2018). To achieve this, post-disaster housing recovery must be grounded in principles that align with the pillars and goals of sustainable development. In the housing context, sustainable development's environmental and economic pillars focus on energy efficiency and resource-conscious rebuilding. In contrast, the social and cultural pillars emphasize a user-oriented approach that addresses affected communities' specific needs and values. Building on this, the study aims to systematically

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review literature to identify post-disaster housing strategies that integrate user-oriented and energy-efficient approaches. It synthesizes this knowledge to develop a multidisciplinary sustainability model that enhances recovery efforts. The following questions guide the review process and ensure the findings align with the goal of promoting sustainable housing recovery solutions in post-disaster contexts.

- What are the key energy-efficient strategies that ensure reduced environmental impact and energy consumption?
- What are the key user-oriented design strategies that improve the adaptability and livability of post-disaster housing, ensuring that it meets residents' diverse needs?

2. Method

The systematic literature review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure the inclusion of relevant studies. PRISMA, developed by Moher et al. (2010), provides a structured approach for conducting systematic reviews by identifying, selecting, and evaluating studies to answer a specific research question. It ensures comprehensive and unbiased analysis, highlights research gaps, and follows four phases: identification, screening, eligibility, and inclusion, guided by a 27-item checklist. This study conducted a literature search using the Scopus database, recognized for its comprehensive and credible coverage (Mongeon & Paul-Hus, 2015; Singh et al., 2021), on February 16, 2025, using advanced queries across titles, abstracts, and keywords without time restrictions. The search strategy included three main term categories. Category A focused on "post-disaster," while Category B covered terms like "temporary housing" and "shelter." Although conceptually distinct, these terms are frequently used in the literature to describe the provision of adequate living spaces in post-disaster situations. As Quarantelli (1995) highlights, the blurred line between sheltering and housing, with sheltering meeting immediate survival needs and housing supporting the return to normalcy. Montalbano and Santi (2023) outline a typical recovery timeline: emergency sheltering (12–48 hours), temporary sheltering (2–30 days), temporary housing (3 months–5 years), and eventual permanent housing within a few years. Category C refers to terms related to approaches in post-disaster housing; C1 included "energy" and "energy efficiency," while category C2 focused on user-oriented terms such as "user," "human," "human-oriented," and "user-oriented." The keyword categories are demonstrated in Table 1. The search process was conducted using two query sets, refined with Boolean operators to ensure comprehensive coverage. Table 2 presents these query sets used during the identification phase. The PRISMA flow diagram (Fig. 1) illustrates the systematic process of identifying, screening, assessing, and selecting studies for inclusion in the review.

Table 1. Keyword Categories.

Category	Keyword
General	Post-disaster
Specific	Temporary housing, Shelter
Approach	User-oriented, Energy Efficiency

Table 2. The query sets used during the identification phase.

Keyword A		Keyword B		Keyword C1	Keyword C2
		Temporary Housing		Energy	User
					OR
		OR			Human
Post-Disaster	AND		AND		OR
					Human-oriented
		Shelter		OR	OR
				Energy Efficiency	User-oriented

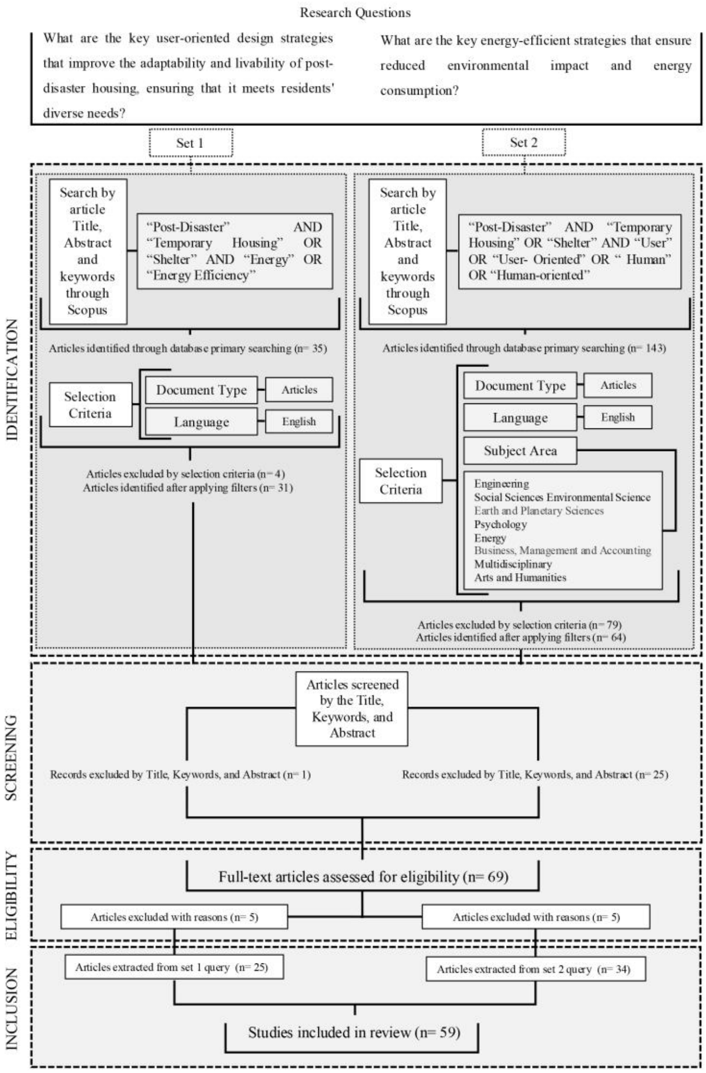

Fig. 1. PRISMA diagram.

3. Results and findings

The systematic literature review results were analyzed using thematic classification, allowing for the identification and organization of concepts across the selected studies. This approach facilitated a structured synthesis of findings for each set (energy-efficient and user-oriented) by grouping them into key themes, which revealed patterns and variations in the existing literature. In each set, several studies span multiple themes, reflecting their broad relevance across various disaster response and recovery aspects.

3.1. Results on the energy-efficient approach in post-disaster temporary housing

This part of the study addresses the research question: *What are the key energy-efficient strategies that ensure reduced environmental impact and energy consumption?* Through a comprehensive review of 25 scholarly sources from the first query set, which are classified into five themes.

3.1.1. Passive design strategies (I)

Post-disaster shelter design now prioritizes climate responsiveness, energy efficiency, and cultural adaptability to enhance relief and long-term recovery. Numerous studies utilize simulation tools and prototypes to evaluate how design choices perform in varied climatic and socio-economic settings. Mojahedi et al. (2019) and Mojahedi et al. (2021) demonstrate through EnergyPlus and DesignBuilder tools that architectural forms like domes and barrel vaults improve thermal comfort and reduce heat gain. Their research also underscores the value of vernacular knowledge in achieving culturally suitable designs.

Nocera et al. (2020) apply Passive House standards in modular shelters for post-earthquake Italy, integrating energy modeling with carbon footprint analysis to advocate for durable, adaptable housing. In tropical settings, da Costa et al. (2023) assess insulation performance in container shelters using BES, linking thermal comfort with economic returns. Modular innovations like the ASH module (Pusceddu et al., 2017) and 3D-printed walls (Khadka et al., 2024) show how flexible systems enhance scalability and climate resilience. Lee et al. (2025) evaluate photovoltaic-integrated mobile homes across Japan, emphasizing passive-active energy strategies for off-grid autonomy. Atmaca (2018) and Moreno-Sierra et al. (2020) focus on climate-responsive envelopes and passive cooling, while Maracchini & D'Orazio (2022) highlight EPS walls for minimizing mechanical reliance. Perrucci and Baroud (2020) stress the relevance of LEED and STEP programs in guiding sustainable temporary housing. Collectively, these studies argue that effective shelter design must go beyond structural safety, embracing passive performance, cultural relevance, and adaptability to climate and disaster types.

3.1.2. Improved comfort and reduced energy consumption (II)

Thermal comfort is a vital element of post-disaster shelter design (Li et al., 2024). Recent research emphasizes performance modeling and simulation tools to enhance energy efficiency, especially in extreme climates. Ibrahim et al. (2023) studied refugee shelters in Iraq, showing that incremental and low-impact construction strategies improve thermal conditions. Similarly, da Costa et al. (2023) and Ibrahim and Baranyai (2021) highlighted the use of PET wool and straw-cob-earth insulation in enhancing comfort when paired with sustainable building methods. Studies by Salvalai et al. (2017) and Pusceddu et al. (2017) demonstrated that recycled materials and multilayer insulation improve heat control in deployable modules, especially where HVAC systems are absent. Song et al. (2016) and Atmaca (2018) emphasized that poor insulation contributes significantly to lifecycle energy consumption, underscoring the need for efficient thermal envelopes. EnergyPlus and DesignBuilder tools are widely used for modeling energy use and optimizing building envelopes. Researchers, including Lee et al. (2025), Mojahedi et al. (2019), Song et al. (2016), and Rapone et al. (2024), applied EnergyPlus to simulate the performance of insulation systems, phase change materials, and shelter forms across multiple climate zones. DesignBuilder, as a visual interface for EnergyPlus, was used by Mojahedi et al. (2021), Moreno-Sierra et al. (2020), and others to evaluate solar gain, form sensitivity, and passive strategies. IDA ICE was applied in studies by Ibrahim et al. (2022, 2023) to validate passive envelope techniques like thermal mass and ventilation for low-tech shelters in Iraq. TRNSYS was used by Pusceddu et al. (2017) and Salvalai et al. (2017) for dynamic thermal simulations of modular shelters using recycled and multilayer materials. Additional tools include eQuest (da Costa et al., 2023), OpenStudio (Khadka et al., 2024), and SketchUp Pro for operational energy modeling. Several scholars combine simulations with experimental tests for real-world validation, including Lv et al. (2024) and Maracchini and D'Orazio (2022).

3.1.3. Traditional and advanced materials (III)

Recent studies highlight the importance of material selection and innovation in post-disaster shelters, focusing on lifecycle performance, cost, and sustainability. Ibrahim and Baranyai (2021) and McConnell and Bertolin (2019) stress local, climate-adapted materials for durability and affordability in resource-constrained settings. Comparative studies by da Costa et al. (2023) and Pusceddu et al. (2017) analyze wall assemblies and insulation systems to optimize thermal efficiency. Material innovation includes recycled plastic, EPS panels, cork insulation, and phase change materials (PCM). Moreno-Sierra et al. (2020) and Salvalai et al. (2017) developed prototypes using waste materials like plastic and skis, while Maracchini and D'Orazio (2022) and Barreca et al. (2022) paired these with passive cooling and prefabrication for better performance.

LCA studies by Zea Escamilla and Habert (2015) and Song et al. (2016) evaluate embodied carbon and energy use, while Atmaca (2017) and Atmaca and Atmaca (2016) compare containers, prefab, and lightweight shelters, showing that lifecycle outcomes often outweigh upfront costs. Cost-focused research, including Nocera et al. (2020) and Lee et al. (2025), reveals that investing in insulation and renewable systems yields long-term savings. Lv et al. (2024) tested a solar-powered emergency shelter (SPES) using flexible PVs and ANSYS-Fluent simulations, showing high thermal resilience in hot, humid climates with mechanical ventilation and evaporative cooling. Solar systems are central to off-grid solutions. Lee et al. (2025) and Li et al. (2024) found PV-powered mobile shelters effective in moderate zones but less viable in colder climates, emphasizing climate-specific energy strategies.

3.1.4. Life cycle assessment (LCA) analysis (IV)

Life Cycle Assessment (LCA) is essential in post-disaster temporary housing studies as it provides a comprehensive evaluation of environmental impacts across a shelter's entire lifespan, from material sourcing to deconstruction. Across reviewed studies, LCA supports informed decisions on materials, energy strategies, and sustainability trade-offs to design low-impact, resilient shelters. Nocera et al. (2020) apply LCA to Passive House shelters in seismic zones, linking thermal performance with environmental footprint. Mojahedi et al. (2021) evaluate nomadic-inspired shelters using LCA principles, emphasizing material and energy efficiency. McConnell and Bertolin (2019) assess container housing in the Bahamas, integrating spatial mapping and life cycle thinking to address both environmental and social impacts.

Atmaca (2017) and Atmaca and Atmaca (2016) compare prefabricated and container units, showing that prefabs offer superior environmental outcomes, with operational energy being the main emissions driver. Song et al. (2016) highlight timber walls as a lower-impact alternative, while Khadka et al. (2024) integrate LCEA with thermal modeling to assess 3D-printed panels. Zea Escamilla and Habert (2015) benchmark 20 global shelter types through multi-criteria LCA to guide material and deployment decisions across contexts. Barreca et al. (2022) examine modular timber shelters with cork insulation and PCM, confirming low carbon and high thermal performance. Together, these studies show that combining LCA with innovative materials and cost analysis is key to creating efficient, adaptable post-disaster housing.

3.1.5. Cost-effective design and economic feasibility (V)

Economic feasibility plays a crucial role in post-disaster housing, particularly when large-scale deployment is needed under limited budgets. Studies increasingly adopt life cycle cost analysis (LCCA), energy modeling, and material evaluation to inform cost-effective designs. Nocera et al. (2020) highlight the balance of energy efficiency and affordability in a passive house prototype for post-earthquake reconstruction in Italy, integrating both operational and embodied carbon considerations for rural modular use. Lee et al. (2025) explore photovoltaic-based mobile housing in Japan, using regional simulations to optimize costs and energy yield. In Brazil, da Costa et al. (2023) compare PET wool and mineral wool insulation in container shelters. While PET wool offers quicker payback (~4 years), mineral wool proves more cost-effective over eight years due to better thermal performance. In Turkey, Atmaca and Atmaca (2016) show that prefabricated shelters outperform containers, with 29.7% lower lifecycle costs and 25.1% lower energy consumption. Zea Escamilla and Habert (2015), comparing 20 designs across 11 countries, found that locally sourced materials reduce embodied costs and emissions, whereas imported steel and concrete raise upfront and long-term expenses. Maracchini and D'Orazio (2022) advocate for EPS-based shelters with passive strategies, natural ventilation, and cool coatings offering the best cost-performance outcomes, especially in hot climates. Overall, long-term affordability is prioritized over short-term savings. Integrating LCCA, regional energy modeling, and localized materials is essential for scalable, sustainable housing.

Table 3. Articles of set 1 (Energy-efficient approach).

Article	Region	Disaster Type*	Thematic Classification
Li et al. (2024)	China	2	II, III
Ibrahim et al. (2023)	Iraq	1	II,
Nocera et al. (2020)	Italy	2	I, II, III, IV, V
Mojahedi et al. (2021)	Iran	2	I, II, IV
Lee et al. (2025)	Japan	2	I, II, III, V
Ibrahim and Baranyai (2021)	Iraq	1	I, II, III, V
da Costa et al. (2023)	Brazil	1	II, III,
Ibrahim et al. (2022)	Iraq	1	I, II, III, V
McConnell and Bertolin (2019)	USA	2	II, III
Li et al. (2024)	Italy	2	III, IV
Pusceddu et al. (2017)	Italy, Japan, Australia, and Iran	1	III
Perrucci and Baroud (2020)	General/Global	2	I, II, III
Atmaca, (2017)	Turkey	1	III, IV
Atmaca, (2018)	Turkey	1	III, IV
Atmaca and Atmaca (2016)	Turkey	1	I, II, IV
Mojahedi et al. (2019)	Iran	2	II, III, V
Lv et al. (2024)	China, Indonesia	2	I, II,
Song et al. (2016)	China	2	II, III
Khadka et al. (2024)	USA	2	II, III, IV
Zea Escamilla and Habert (2015)	General/Global	2	I, II, IV
Moreno-Sierra et al. (2020)	USA, Peru, Philippines	2	III, IV, V
Maracchini and D'Orazio (2022)	Italy, India, Brazil	1	I, II, III
Barreca et al. (2022)	Italy	1	I, II, III, V
Rapone et al. (2024)	Italy, Netherlands	2	II, III, IV
Salvalai et al. (2017)	Italy	1	II, III

* Disaster Type Codes: 1 = Natural and Man-Made; 2 = Natural

3.2. Results on the user-oriented approach in post-disaster temporary housing

This part of the study addresses the research question: *What key user-oriented design strategies enhance the adaptability and livability of post-disaster housing to meet residents' diverse needs?* Through a comprehensive review of 34 scholarly sources from the second query set, which are classified into six themes.

3.2.1. Human rights (VI)

Several studies stress that post-disaster housing must be understood as a human rights issue rather than merely a technical response. George et al. (2022) emphasize the importance of recognizing shelter as a space that ensures dignity, privacy, and protection, while Carver (2011) critiques the ambiguity in international law concerning a clear right to post-disaster housing, calling for stronger legal frameworks. Roosli and Baharum (2012) similarly view the failure to deliver appropriate housing in post-disaster recovery as a violation of basic living standards and a disregard for community agency. Juran (2012) underscores how disasters exacerbate gender-based inequalities, leading to heightened violations of women's rights in shelter access, sanitation, and safety. Imperiale and Vanclay (2019) argue that centralized disaster governance that undermines public participation and transparency erodes civic rights. Likewise, Kennedy et al. (2008) highlight that the "build back better" agenda often failed to include marginalized groups, limiting its ability to fulfill the promise of equitable and rights-based recovery. Together, these works call for a rights-based, inclusive, and participatory framework in post-disaster housing and recovery.

3.2.2. Psychological well-being and social cohesion (VII)

Psychological well-being and social cohesion are increasingly recognized as central to in the context of post-disaster housing recovery. Researchers emphasize that when displaced individuals are able to adapt or personalize their temporary housing, it fosters a sense of control and emotional stability (Duru & Sarıkaya, 2024). Well-regulated housing environments characterized by thermal comfort and spatial openness play a vital role in alleviating stress and enhancing psychological recovery (Li et al., 2023). Prolonged displacement can result in social isolation and emotional strain, underscoring the need for housing environments that encourage social connection and community engagement (Gagné, 2020). Design strategies that balance privacy with shared spaces can promote interaction and reduce tension among residents (Kim et al., 2022; Bris & Bendito, 2019). Social capital, whether among close-knit groups or wider community networks, plays a vital role in emotional recovery and reintegration, particularly when supported by environments that facilitate ongoing interaction and support (Rahill et al., 2014). Moreover, involving residents in the planning and design of shelters improves satisfaction, fosters trust, and strengthens the collective sense of community (Opdyke et al., 2019).

3.2.3. Socio-cultural resilience and community-based approaches (VIII)

Socio-cultural resilience and community-based approaches are widely recognized as essential to effective post-disaster housing recovery. Scholars emphasize that housing must go beyond physical shelter to support cultural continuity and community identity. Designs informed by local traditions and shaped through participatory processes foster a stronger sense of belonging and long-term usability (Hadafi & Fallahi, 2010; Rahmayati, 2016; Idham & Andriansyah, 2021). Engaging residents in planning helps reconcile professional design strategies with lived experiences, ensuring housing solutions are relevant and respectful of local values (Tan & Özcan, 2024; Opdyke et al., 2019). Additionally, bonding and bridging social capital reinforce emotional recovery and enable communities to mobilize resources and support systems (Rahill et al., 2014). Several scholars emphasize that standardized, top-down recovery models often overlook these dynamics, undermining local agency and cultural relevance (Kennedy et al., 2008; Curato, 2018). A systems-based perspective further underscores the importance of integrating cultural, social, and adaptive dimensions into the built environment to achieve sustainable recovery (Elinwa & Moyo, 2018).

3.2.4. Technology and innovative design (IX)

Technology and innovative design play a critical role in advancing post-disaster housing by enabling flexible, efficient, and locally appropriate solutions. Computational tools such as genetic algorithms and automated planning systems improve layout optimization, site allocation, and decision-making under constraints (Karaoğlan & Alaçam, 2019; El-Anwar et al., 2009). Prefabricated and modular construction methods help expedite reconstruction without compromising quality, making them suitable for large-scale deployment (Gunawardena et al., 2014). Mobile and reconfigurable shelters offer logistical advantages and adapt to changing user needs over time (Cerrahoğlu & Maden, 2024; Torus & Şener, 2015). Innovations in material use, such as 3D printing with local soil, demonstrate how sustainable practices can be combined with advanced techniques to reduce environmental impact and enhance self-sufficiency (Venturi et al., 2019). Moreover, integrating passive design strategies with culturally appropriate forms ensures that housing supports both immediate functionality and long-term community relevance (Shih & Ravina, 2020). Together, these approaches underscore the importance of design innovation in creating effective and inclusive housing responses to disaster.

3.2.5. Evaluation and optimization frameworks (X)

Evaluation and optimization frameworks are essential for ensuring informed, context-sensitive decisions in post-disaster housing recovery. These approaches often incorporate computational models and decision-support tools to optimize factors such as cost, location, and resource allocation, thereby improving the overall planning process (El-Anwar et al., 2009; El-Anwar, 2013). Some frameworks are grounded in sustainability or performance requirements, linking housing design to environmental efficiency, user needs, and adaptability (Hosseini et al., 2020; Montalbano & Santi, 2023). Others use indicator-based methods to assess shelter quality regarding safety, affordability, and cultural relevance, providing practical guidance for policy and implementation (Nath et al., 2016). Additionally, comparative evaluations of spatial and structural criteria offer adaptable standards that can be applied across varying disaster contexts (Beatini et al., 2022). Collectively, these frameworks enhance the reliability, sustainability, and responsiveness of housing recovery strategies.

3.2.6. Governance, strategic planning, and community participation (XI)

Effective governance and strategic planning are essential for equitable and coordinated post-disaster housing recovery. Scholars emphasize the value of participatory processes that integrate community knowledge, ensure transparency, and strengthen institutional trust. Involving local populations in planning improves satisfaction and supports the long-term success of housing solutions (Omidvar et al., 2011; Montalbano & Santi, 2023). Governance models that encourage deliberation and shared agency are considered more effective than centralized approaches, which often lack accountability and exclude those most affected (Curato, 2018; Imperiale & Vanclay, 2019). The importance of planning before disaster strikes is also underscored, particularly for defining responsibilities and preventing fragmented responses (Johnson, 2007). Bridging technical expertise with community perspectives further enhances the relevance and responsiveness of recovery strategies (Kelman et al., 2011). Ultimately, post-disaster housing governance should be guided by frameworks that promote dignity, inclusion, and proactive collaboration across sectors (George et al., 2022).

Table 4. Articles of set 2 (User-oriented approach).

Article	Region	Disaster Type*	Thematic Classification
George et al. (2022)	General/Global	1	VI, XI
Carver (2011)	General/Global	1	VI
Roosli and Baharum (2012)	Malaysia	2	VI
Juran (2012)	India	2	VI
Duru and Sarıkaya (2024)	Turkey	2	VII
Hadafi and Fallahi (2010)	Iran	2	VIII
Li et al. (2023)	China	2	VII
Gagné (2020)	Japan	1	VII
Kim et al. (2022)	USA, Australia, Japan	1	VII
Bris and Bendito (2019)	Japan	2	VII
Kelman et al. (2011)	General/Global	1	XI
Shih and Ravina (2020)	Philippines	2	IX
Elinwa and Moyo (2018)	General/Global	1	VIII
Rahmayati (2016)	Indonesia	2	VIII
Idham and Andriansyah (2021)	Indonesia	2	VIII
Tan and Özcan (2024)	Turkey	2	VIII
Rahill et al. (2014)	Haiti	2	VII, VIII
Karaoğlan and Alaçam (2019)	General/Global	1	IX
Cerrahoğlu and Maden (2024)	General/Global	1	IX
Torus and Şener (2015)	Turkey	2	IX
Beatini et al. (2022)	General/Global	1	X
Venturi et al. (2019)	General/Global	1	IX
Gunawardena et al. (2014)	General/Global	2	IX
Hosseini et al. (2020)	Iran, Indonesia	2	X
Nath et al. (2016)	General/Global	2	X
El-Anwar et al. (2009)	General/Global	2	IX, X
El-Anwar (2013)	USA	2	X
Imperiale and Vanclay (2019)	Italy	2	VI, XI
Kennedy et al. (2008)	Indonesia, Sri Lanka	2	VI, VIII
Johnson (2007)	Turkey, Colombia, Japan, Greece, Mexico, Italy	2	XI
Curato (2018)	Philippines	2	VIII, XI
Opdyke et al. (2019)	Philippines	2	VII, VIII
Omidvar et al. (2011)	Iran	2	XI
Montalbano and Santi (2023)	General/Global	1	X, XI

* Disaster Type Codes: 1 = Natural and Man-Made; 2 = Natural

4. Discussion

The reviewed literature in set 1 indicates that effective post-disaster housing is contingent on incorporating energy-efficient strategies that align with sustainable development's environmental and economic pillars. The derived strategies include adopting passive design techniques; improving comfort and reducing energy consumption; utilizing both traditional and advanced materials to support contextual adaptability and resource efficiency; and developing cost-effective design solutions that are essential for ensuring financial sustainability, particularly in resource-constrained post-disaster settings. Additionally, the integration of life cycle assessment (LCA) is a critical tool for evaluating the long-term environmental performance and overall sustainability of housing systems throughout their lifespan. The reviewed literature in set 2 consistently emphasizes the integration of psychological, emotional, and ethical considerations into post-disaster housing, aligned with the social and cultural pillars of sustainable development. The derived user-oriented strategies are: human rights; psychological well-being and social cohesion; socio-cultural resilience and community-based approaches; technology and innovative design; evaluation and optimization frameworks; and governance, strategic planning, and community participation.

Consequently, the model for sustainable post-disaster housing recovery (Fig. 2) centers on energy-efficient and user-oriented strategies, aligned with the four pillars of sustainable development and relevant goals to ensure holistic, long-term recovery. The energy-efficient strategies align with several sustainable development goals (SDGs), including SDG 7- Affordable and Clean Energy, SDG 9- Industry, Innovation and Infrastructure, SDG 12- Responsible Consumption and Production, and SDG 13- Climate Action. The user-oriented strategies support SDG 3- Good Health and Well-being, SDG 5- Gender Equality, SDG 6- Clean Water and Sanitation, and SDG 10- Reduced Inequalities. Both energy-efficient and user-oriented strategies align with SDG 11- Sustainable Cities and Communities, which advocates for the inclusive, safe, resilient, and sustainable built environment. Accordingly, these strategies support recovery efforts that are socially and culturally inclusive, environmentally responsible, and economically viable while also being better equipped to withstand future challenges.

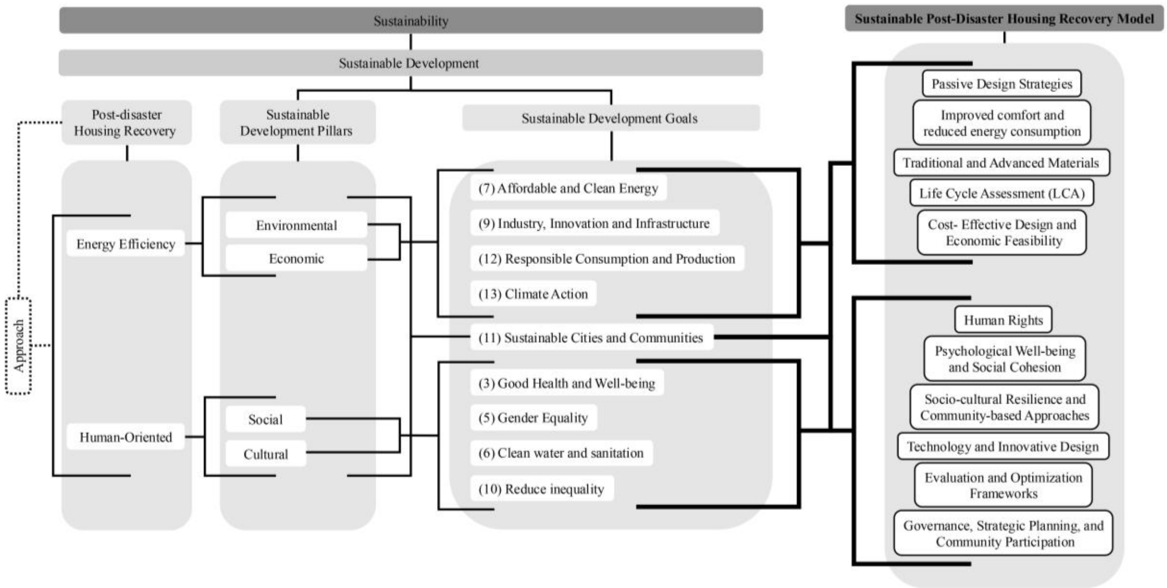

Fig. 2. Multidisciplinary sustainable post-disaster housing recovery model.

5. Conclusion

This study contributes to the field of sustainable post-disaster housing recovery by proposing a multidisciplinary model that integrates energy-efficient and user-oriented strategies. Based on a systematic review of 59 academic sources, 11 strategic themes were identified, five related to energy efficiency and six to user-oriented strategies. These themes highlight the need for recovery approaches that address environmental, economic, social, and cultural dimensions. Collectively, these strategies offer a foundation for sustainability in post-disaster contexts and inform a comprehensive, SDGs-aligned model adaptable to diverse settings. The study provides practical insights for researchers and professionals in architecture and urban studies, supporting the development of equitable, adaptable, and context-sensitive housing recovery solutions. Future research could further validate the proposed model through empirical case studies, simulation-based evaluations, or stakeholder-based participatory assessments to examine its applicability and effectiveness across different post-disaster contexts.

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Definition and typology of nomadic architecture (Case study: Iranian nomads)

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Abstract. Nomadic architecture is one of the significant aspects of Iran's architectural heritage, encompassing both tangible and intangible cultural values. This study aims to define "Nomadic Architecture" in a comprehensive manner that includes all nomadic structures. A better understanding of nomadic architecture requires attention to its diverse forms and should not be limited to temporary housing. Information for this study has been collected through library research and field surveys of nomadic habitats. The research methodology is descriptive-analytical, focusing on analyzing the collected data. The case study of this research includes nomadic communities in Iran. The nomadic community exhibits diverse and valuable architectural forms. Temporary housing structures (such as black tents, shelters, and yurts) are just one type of nomadic architecture. A typology of nomadic architecture should be based on models or frameworks that encompass all architectural forms. Nomads, due to their migratory nature, construct temporary, semi-temporary, and permanent structures. These various types of nomadic architecture can be categorized based on a spatial-temporal model. Additionally, nomadic architecture is multifunctional, providing spaces for housing, livestock shelters, fortresses, marketplaces, playgrounds, and tombs. These architectural types can also be classified using a functional model. Nomadic architecture is not limited to temporary housing structures such as black tents and shelters. It encompasses a wide range of diverse structures, including black tents, shelters, yurts, fortresses, tombs, marketplaces, masonry housing, playgrounds, and livestock shelters

Keywords: Architecture; Nomads; Nomadic architecture; Nomadic structures

1. Introduction

Modes of human existence, currently encompasses an estimated 30 to 40 million people worldwide (Vundi and Koome, 2023). Practiced across various continents for the efficient use of natural resources and environmental stewardship, this lifestyle has not only fulfilled the subsistence needs of human societies but has also endured as a cultural, economic, and social system. Core features of nomadism—mobility, continuous interaction with nature, and adaptable livelihood strategies—have distinguished it as a unique form of human life.

In Iran, the nomadic lifestyle has a deep-rooted history, with some sources tracing its origins to eight thousand years ago (Amanollahi Baharvand, 2004). The distinct natural and climatic conditions of the Iranian plateau have long facilitated the development and continuity of nomadic practices. Even the migration of Aryan tribes to this region and their choice to settle there highlight its climatic compatibility with nomadic life. Up until the early 14th century CE, Iranian governance was closely linked to nomadic societies, whose influence on the nation's economic, military, and social transformations remains undeniable (Shabani, 2011). Through activities such as animal husbandry, agriculture, and sustainable resource management, Iranian nomads have historically played a key role in ensuring food security and defending territorial boundaries (Mirtaghian Roudsari, 2023; Darvishi and Khodadad, 2022).

Among the most significant elements of nomadic culture is the architecture specific to these communities. Designed in response to the evolving needs of nomadic life and in harmony with the climate, these structures are simple, portable, lightweight, and efficient. They serve not only as seasonal and mobile shelters but also as spaces for livestock, food storage, religious practices, protection, and subsistence activities.

Nomadic architecture—such as the Siah Chador, Koper, Alachiq, and other forms—represents a synthesis of lived experience, indigenous knowledge, craftsmanship, and environmental adaptation. The use of local and renewable materials, efficient resource utilization, and climate-responsive spatial design are key characteristics.

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Beyond its practical and ecological aspects, this architecture also conveys aesthetic, symbolic, and cultural meanings.

Despite its significance, nomadic architecture has often been narrowly defined in previous studies, primarily as temporary housing, with its broader forms and functions overlooked. This research seeks to redefine "nomadic architecture" more comprehensively and to classify the diverse architectural expressions found among Iranian nomadic groups. Through the analysis of documentary and field data, this study aims to provide a holistic understanding of nomadic architecture and to establish it as an essential component of Iran’s cultural, historical, and architectural heritage.

Table 1. Research background

Researcher(s) / Year	Title of Research	Findings / Results
Filberg (1993)	Black Tent: The Shelter of Nomads and Semi-Nomads in the Course of History	The researcher explores the types of nomadic tents in various regions, studying similarities and differences in nomadic dwellings among different tribes.
Kiani (1997)	Black Tents: A Study of the Life of the Qashqai Tribe	Nomadic housing is divided based on color into 'black tents' and 'colored tents,' differentiated by size, material, and function.
Danaei-Nia and Il-Begipour (2017)	Cultural Landscape Features of the Bakhtiari Nomads and Its Impact on Nomadic Architecture	The study identifies cultural factors affecting Bakhtiari nomadic housing and categorizes the architecture of seven major Iranian tribes based on these cultural landscape elements.
Aghai, Karami and Hasari (2018)	Typology of Architecture in Pastoral Nomadic Communities	This research classifies nomadic settlements using three models: spatial-temporal, socio-economic, and historical-cultural. It also compares parts of the black tent across different types.
Ranjbar and Mahmoudi (2020)	Morphology of Black Tents Among Nomads in Southwest Iran	The study analyzes cultural differences and similarities in black tent morphology among Kurdish and Bakhtiari tribes, considering climate, hospitality, ceremonies, protection, and aesthetics.
Turkmen and Sultan-Zadeh (2020)	Cultural Reflection in the Architecture of Nomadic Settlements – Case Study: Turkmen Nomads	The research identifies cultural components of the Turkmen tribe through symbols and signs in architecture and categorizes Turkmen tents into 'Chatma,' 'Got Takma,' and 'Aq Owi and Qara Owi' based on function, color, and duration of stay.
Mohsen Afshari (2021)	Typology of the Black Tent Architecture of the Qashqai Tribe	The research introduces and analyzes Qashqai black tent architecture and examines its different types across four scenarios: summer, winter, migration, and sudden weather changes.
Andrews (1997)	Nomad Tent Types in the Middle East: Framed Tents	Covers a wide range of nomadic tents in the Middle East, categorizing them into 56 types based on structural form and ethnic group.
Hassas and Borucka (2020)	A Comparative Study of Iranian Nomadic Housing	Investigates black tents as 'homes,' comparing and classifying them in seven different Iranian tribes by form, material, structure, space, and interior design.
Mojahedi, Vafamehr and Ekhlassi (2021)	Designing Post-Disaster Temporary Housing Inspired by Indigenous Nomadic Housing in Iran	Proposes replacing standard temporary shelters with indigenous nomadic models (Kapar, Moozif, Alachiq), highlighting energy efficiency and comparing their consumption.

2. Research background

Research on nomadic architecture has predominantly centered on identifying, documenting, and classifying the temporary dwellings of nomadic communities—especially structures such as the Siah Chador (black tent) and Alachiq, which serve as central elements of seasonal settlements. These studies have primarily examined temporary nomadic architecture from cultural, climatic, structural, and functional perspectives.

In this regard, Filberg (1993) was among the earliest scholars to study the tents of Middle Eastern nomads, classifying them based on cultural and climatic patterns. Kiani (1997) focused on the tents of the Qashqai nomads, categorizing them according to their structure and morphology. Building upon this foundation, Danaeinya and Ilbegipour (2017) examined nomadic housing through the lens of cultural patterns.

Other notable contributions include the work of Aghaei, Hesari, and Karami (2018), who analyzed Qashqai nomadic settlements using a spatial-temporal framework, proposing a five-fold classification. Similarly, Afshari (2021) developed a typology of Qashqai Siah Chador architecture in four distinct categories. Ranjbar and Mahmoudi (2020) investigated Siah Chadors among Kurdish and Bakhtiari nomads from both cultural and climatic standpoints. Torkaman and Soltanzadeh (2020) also classified the Alachiqs of Turkmen nomads into three groups based on their functional and cultural characteristics.

Internationally, several studies have engaged with this subject as well. Andrews (1997), for example, examined nomadic architecture in the Middle East from structural and climatic perspectives. Hassas and Borucka (2020) classified Siah Chadors used by nomads across various countries according to structural typologies. Similarly, Mojahedi, Vafamehr, and Ekhlassi (2021) conducted a comparative study of temporary nomadic architecture among three different tribes.

A review of this body of research reveals that most investigations have focused almost exclusively on the residential and temporary aspects of nomadic architecture. Few have addressed the broader scope of nomadic built environments, including non-residential structures, communal spaces, livestock-related facilities, and the cultural or social functions embedded within these architectural forms.

Accordingly, the present study seeks to move beyond the traditional framework of temporary housing by addressing the central question: "What is nomadic architecture, and on what basis can its various types be identified and classified?" With this objective, the research aims to identify and categorize all forms of nomadic architecture—both residential and non-residential. In doing so, the study employs cultural, climatic, structural, and functional approaches, as well as spatio-temporal patterns, as the primary analytical frameworks.

3. Research methodology

This study adopts a qualitative methodology and pursues a dual objective—both fundamental and applied. On the one hand, it seeks to expand theoretical knowledge in the field of nomadic architecture; on the other, its findings aim to support the identification, conservation, and promotion of the tangible and intangible cultural heritage of Iranian nomads. Accordingly, the research exhibits a hybrid nature, combining theoretical inquiry with practical application.

For data collection, a combination of library research and fieldwork methods was utilized. In the initial phase, written sources—including books, academic articles, field reports, and historical documents—were reviewed to establish the theoretical foundations of the study and to examine prior research. In the subsequent phase, the researcher conducted extensive fieldwork across various nomadic regions in Iran. Through direct observation and immersion in nomadic environments, qualitative data were gathered regarding different types of handmade nomadic structures. These data capture the physical, structural, functional, and cultural characteristics of architectural forms used by nomads during different phases of seasonal migration.

The collected data were then analyzed using a descriptive-analytical approach, which allowed for detailed documentation of nomadic architecture and examination of the interrelations among its cultural, climatic, functional, and structural components. This process facilitated the identification of recurring patterns as well as architectural diversity within nomadic life.

Ultimately, the study synthesized these findings to address its central research question and to identify and classify various types of nomadic architecture. The result is the formulation of a conceptual and practical framework for analyzing nomadic architecture in the Iranian context.

4. Geographical scope

The geographical scope of this research covers various regions across Iran where nomadic communities are traditionally based. These areas primarily include mountainous terrains, plains, and seasonal pastures (yaylāq and qishlāq), which offer a wide range of natural and climatic conditions favorable to nomadic lifestyles. Field investigations and sampling of handmade nomadic structures were carried out in these diverse settings.

The selected regions span several provinces, each chosen for its distinctive climatic, cultural, and historical relevance to nomadic habitation. These include:

The western provinces of East Azerbaijan and West Azerbaijan, home to Shahsevan, Kurdish and other nomadic groups.

The central and southern provinces of Fars and Kohgiluyeh and Boyer-Ahmad, where Qashqai and Bakhtiari nomads have historically resided.

This geographical coverage was intentionally chosen to represent the enduring diversity of nomadic cultures in Iran, making it well-suited for identifying and analyzing a wide array of nomadic architectural typologies.

5. Research findings

According to the Amid Dictionary, the term Ashāyer (nomads) refers to tribal groups who earn their livelihood primarily through pastoralism (Amid, 2014). Nomadism denotes a lifestyle in which people sustain themselves by raising livestock and using agricultural products, migrating seasonally in search of natural pastures. This way of life has existed in Iran since ancient times and continues to persist today. In the Iranian context, several terms—such as Ashāyer (tribes), Kuchneshin (nomads), Eliyāti (tribal people), Biābangard (desert wanderers), Gallehdār (herders), Goluneh, and Māldār-e Chādarneshin (tent-dwelling herdsmen)—are used to describe different aspects of nomadic life (Emanollahi Baharvand, 1981). In this study, the term Ashāyer is employed to refer to nomadic communities.

5.1. Nomadic architecture

Nomadic architecture is not merely a form of shelter or a temporary structure—it is an inseparable component of the broader nomadic way of life (Trisno, Husin, and Lianto, 2023). Nomadic communities across all continents design and build structures tailored to their living needs, often using locally available materials. Like other forms of informal architecture, nomadic architecture centers on human needs and prioritizes practicality and adaptability. It encompasses a wide spectrum, from simple utilitarian forms to elaborate cultural expressions (Trisno et al., 2023).

The origins of nomadic architecture trace back to early human societies that migrated in search of food, water, and shelter. In diverse geographical settings, nomadic groups developed unique architectural traditions suited to their specific environmental and cultural conditions. Well-known examples of such adaptive architectural forms include the Mongolian yurt, North African tents, and Native American tipis.

Hassas (2021) defines nomadic architecture as the “home” of nomadic people, challenging the notion that tents are merely temporary shelters. She provocatively asks: how can a structure that meets human needs day and night for centuries still not be regarded as a 'home'?

Aghaei, approaching the subject from an archaeological standpoint, argues that nomadic architecture is shaped by the need to adapt to the environment—prioritizing energy conservation, protection from the elements, and the safety of both people and livestock (Aghaei, Hesari, and Karami, 2018).

Nomadic architecture specifically refers to structures designed and constructed by nomadic societies. These structures vary in form and function according to cultural traditions, climatic conditions, livelihoods, and the scale of migration. Due to the mobile nature of nomadic life, this architecture typically emphasizes transportability, simplicity, lightness, and flexibility (Soleymani Amirshkari, 2019).

In this study, nomadic architecture is defined as the art and practice of designing and building all types of structures created by nomadic communities. This encompasses a diverse range of spaces and forms, including Siyāh-Chādor (black tents), masonry dwellings, Ālāchigh (felt tents), Pilevari caravanserais, fortresses, animal shelters, communal gathering spaces, and play areas.

5.2. Typology in architecture

In architecture, a type is defined as a schema or prototype in which the common characteristics of a group of buildings are identifiable (Memarian and Tabarsa, 2013). The concept of type and typology in architectural discourse was first introduced by Ghiyath al-Din Jamshid Kashani in the 9th century AH (15th century CE). In his book Miftah al-Hesab, he referred to various traditional architectural elements—such as arches, vaults, and domes—using the term “qesmat” (meaning section or category), which conceptually aligns with the contemporary notion of type.

Architectural typology as a formal discipline began in 18th-century France, focusing on both form and function. During this period, Laugier explored the concept of the primitive hut, and later, in collaboration with professors at the École Polytechnique in Paris, developed typological classifications based on theories of independent origins and the gradual evolution of architectural characteristics (Durand, 2000). His definition of type was largely quantitative and mechanistic, utilizing coded systems to analyze architectural forms. The rationalist logic of that era in typology laid the foundation for later eclectic movements (Moneo, 1978).

In general, architectural typology serves as a framework for organizing and analyzing buildings based on shared features. This approach enables broader interpretations by integrating various chains of thought and diverse perspectives. In Iran, over the past three decades, typological studies—especially in the field of vernacular architecture—have garnered increasing attention, supported by institutions such as the Building and Housing Research Center and the Housing Foundation of the Islamic Revolution (Soltanzadeh and Ghaseminia, 2011).

In this context, Ardalan and Bakhtiar emphasize the symbolic and semantic dimension of typology from the perspective of the archetype. They assert that the archetype possesses a transcendent essence that is reflected in various physical forms within the material world (Ardalan and Bakhtiar, 1973). In sum, researchers have explored architectural typology from both morphological and physical as well as semantic and symbolic perspectives.

5.3. Nomadic architecture and its typology

Nomadic architecture, as a tangible reflection of the culture of nomadic communities, symbolizes human adaptation to the natural environment and innovation in utilizing local resources. This architectural form embodies both tangible and intangible cultural heritage, encompassing diverse values and dimensions, including historical, aesthetic, social, and environmental aspects. To gain a comprehensive understanding of nomadic architecture, typological analysis must consider not only the morphological and physical dimensions but also the structural and foundational (genotypic) characteristics. In this study, the typology of nomadic architecture is based on its genotypic features, with a particular focus on its fundamental structures.

Nomadic communities rely on the natural resources available in their ecosystems to construct their architecture (Trisno et al., 2023). One of the most distinctive aspects of nomadic architecture is its close relationship with the environment. By utilizing local and natural materials such as wool, wood, and reed, and designing structures that adapt to climatic conditions, this architecture exemplifies sustainability and respect for nature. Additionally, the flexibility of these designs enables easy relocation and effectively responds to the seasonal and livelihood needs of nomadic life.

Today, nomadic tourism is recognized as a distinct form of tourism characterized by unique spatial patterns. This type of tourism, particularly in the form of ecotourism, has gained significant importance and attracted substantial international investment (Yousefi, Tamassoki, and Tamassoki, 2022). Nomadic ecotourism, in particular, plays a beneficial economic and cultural role, generating positive impacts for both nations and nomadic communities.

To understand nomadic architecture more precisely, it is essential to systematically classify the structures used by these communities based on a range of distinct characteristics. This typology is influenced by factors such as the level of mobility among nomads, patterns of pasture ownership, climatic conditions, cultural traits, livelihood strategies, and the spatial functions of the structures. One of the most important distinguishing features of nomadic architecture, in contrast to sedentary architecture, is mobility. Nomadic groups are constantly on the move, responding to seasonal changes and environmental conditions, and establish temporary settlements in specific parts of their territory.

Unlike the architecture of rural and urban communities, nomadic architecture is more dependent on natural, geological, and climatic factors. The materials used in constructing these structures are sourced from local and natural environments, including goat hair and wool, wood, reeds, soil, lime, stone, and tree branches. These materials are not only accessible and renewable but also fulfill the needs of a mobile and temporary lifestyle.

5.4. The "Spatio-Temporal" and "Functional" models in nomadic architecture

Nomadic architecture is a direct reflection of the nomadic lifestyle—a way of life shaped by regular and seasonal migrations within natural landscapes, closely intertwined with the environment, climate, and subsistence economy. In this context, space functions not only as a physical container for habitation but also as an integral part of survival mechanisms, production systems, and cultural rituals. Therefore, typologizing nomadic structures requires a model capable of effectively capturing this complexity and dynamism. The "spatio-temporal" and "functional" models provide appropriate analytical frameworks for this purpose, as they align with the ecological and cultural realities of nomadic communities.

Typologizing nomadic architecture based on these two models aims to identify and classify the fundamental structures and spatial orders governing this architectural tradition. Despite differences in form, material, and climatic context, these structures follow a shared internal logic. This typology can be situated within the conceptual realm of the "genotype," as it analyzes the deep structural layers of nomadic architecture by focusing on stable patterns and space-organizing algorithms. In contrast, the external and variable manifestations of this architecture—shaped by interactions with the environment, climate, and local cultures—can be interpreted as "phenotypes." In other words, typology based on spatio-temporal and functional models reflects a shared spatial and conceptual system among nomadic communities, expressed in diverse forms and indicative of genotypic characteristics.

5.5. The Spatio-Temporal Model

The spatio-temporal model, rooted in the inherently mobile nature of nomadism, allows for the classification of structures based on their geographic location (summer pastures, winter pastures, and migratory routes) and the duration of their use (temporary, seasonal, semi-permanent, or permanent). This model also considers the adaptability of structures to climatic conditions, access to natural resources, and the need for portability or durability. In other words, nomadic architecture cannot be understood or analyzed without considering the spatial and temporal context of settlement.

This section of the study investigates the spatio-temporal model in the context of Iranian nomadic architecture. One of the key characteristics of this architecture is its strong connection to seasonal mobility and climatic variability. That is, at each stage of migration, pastoral nomadic communities adapt their architectural structures significantly in response to factors such as weather conditions, pasture availability, and subsistence needs.

Iranian nomadic groups typically occupy different geographical zones throughout the year. Specifically, during winter, they settle in low-altitude winter pastures (qeshlaq); in autumn, they move to mid-altitude slopes;

in spring and part of the summer, they migrate to highland summer pastures (yaylaq); and during the remainder of the summer, they occupy cold intermountain plains. These spatial shifts not only directly influence their lifestyle and livelihood strategies but also result in significant architectural transformations in the structures they use.

A notable example of architectural change during seasonal migrations is the transformation in the design and structure of the black tent (siah chador). At each stage of migration (yaylaq, qeshlaq, and transition), black tents exhibit specific features, including variations in platform shape and the location of hearths, based on the geographic and climatic context. These changes demonstrate the nomadic architecture's precise adaptation to the spatio-temporal conditions of nomadic life.

Consequently, Iranian nomadic architecture can be categorized into three general types based on spatial and temporal conditions: temporary, semi-temporary, and permanent. This classification aligns with the three main stages of nomadic settlement—yaylaq, migration, and qeshlaq—and accurately reflects the architecture's responsiveness to the shifting spatial and temporal conditions of nomadic existence.

This typology, based on geographical locations and usage duration, comprehensively explains the complex processes underlying nomadic architecture and illustrates how these communities' structural systems adapt to seasonal and climatic changes.

5.6. Typology of nomadic structures in Iran

Based on research findings, nomadic architectural structures in Iran can generally be classified into three categories: transportable, immovable, and semi-transportable structures. Each category reflects specific features shaped by subsistence needs, geographical locations, and seasonal changes inherent to nomadic life.

5.6.1. Transportable structures

Transportable structures are those designed for easy assembly and disassembly due to their temporary nature, allowing for mobility by nomadic groups. These structures are typically made from soft, natural materials readily available to nomads. Notable examples include black tents (siah chador), kapar huts, kuar, and various animal shelters—all made from materials such as leather, specialized fabrics, and wood. These structures are primarily used during migration and seasonal relocation, and are characterized by simple, functional designs that accommodate quick and easy movement.

5.6.2. Immovable structures

Immovable structures are usually constructed in fixed locations within yaylaq or qeshlaq areas and remain permanently in place. These are typically built in regions revisited annually by nomads and often include winter structures in cold mountainous areas. Built from locally sourced and durable materials such as wood, stone, mud, and lime mortars, they include khan residences, shrines, village-like homes, animal shelters, and small fortifications. Along migratory routes, defensive shelters were also constructed—used by armed guards to protect the tribe during transit.

5.6.3. Semi-transportable structures

Semi-transportable structures combine features of both mobile and immobile architecture. Typically, the foundation and walls—requiring durability—are built from hard materials, while the roof and coverings are made from soft, temporary materials. A prominent example includes the stone-enclosed black tents used in cold qeshlaq regions, where traditional fabric covers (chugh) are replaced by stone barriers to better resist cold and wind. These hybrid structures provide resistance in harsh environments while maintaining the flexibility needed for seasonal reconstruction or relocation.

This classification clearly illustrates the diversity and complexity of nomadic architecture in Iran—ranging from simple, temporary shelters to resilient, permanent constructions. Each structure is crafted from specific materials in response to seasonal needs and geographical conditions. This categorization enhances our understanding of how nomadic architecture interacts with the environment and supports efforts to preserve and sustain these unique architectural forms.

5.7. Functional pattern of nomadic architecture

The functional pattern of nomadic architecture is one of the most important aspects of this architectural style, directly linked to the daily needs of nomadic communities. This pattern, as one of the fundamental components of nomadic architecture, takes into account not only the physical needs but also the cultural, social, and environmental dimensions of nomadic societies. Nomadic architectural structures are designed to meet all livelihood and cultural needs at each stage of movement and settlement in various regions.

5.7.1. Design of residential spaces
Residential structures in nomadic architecture typically consist of spaces designed for temporary yet comfortable habitation. These spaces are specifically built for short-term movement and settlement in different areas. The design of these spaces considers essential needs such as heating, ventilation, and protection against climatic conditions. For instance, black tents, one of the most recognized residential structures in nomadic architecture, are designed with flexible structures and indigenous materials like wool and leather, specifically to adapt to various climatic and geographical conditions.

Black tents, as temporary living spaces, are commonly used during the migration from one region to another. The design of these structures is such that they can be easily erected and dismantled, which is an essential feature for nomadic life. This type of architecture enables nomads to adjust their living space at any time and place as needed.

5.7.2. Livelihood and productive spaces
Alongside residential spaces, there are other areas in nomadic architecture specifically designed for livelihood activities. Since animal husbandry and agriculture are the main sources of income for nomads, nomadic architecture includes spaces for livestock housing, food storage, workshops, and even small areas for food preparation and cooking.

Livestock spaces are of particular importance and must be designed to protect animals from natural threats and wild animals while also providing for their nutritional needs. Typically, these spaces are designed as storage areas made of wood or matting, allowing for proper ventilation and protection from extreme temperature changes.

5.7.3 Ritual and social spaces
Another aspect of the functional pattern of nomadic architecture is the social and ritual spaces. These areas, in addition to meeting daily needs, serve as places for social interaction and cultural and ritual activities. In nomadic societies, many cultural rituals, such as festivals, religious ceremonies, and social gatherings, take place in these spaces.

These spaces may include larger tents or pavilions used for holding ceremonies and social gatherings. In some cases, these structures are considered gathering places for tribes and clans and are temporarily constructed in specific areas of the nomads' territory.

5.7.4. Service-commercial structures
Nomadic architecture, aside from residential aspects, also includes service and commercial dimensions. Nomads create spaces for temporary markets, rest stops at caravanserais, and trade connections with other groups. Nomadic markets are among the prominent examples of these structures, often set up in early spring in some areas. These markets not only serve as places for buying and selling nomadic products but also offer opportunities for cultural and social exchange between nomads and other segments of society.

Finally, the architecture of Iranian nomads, particularly in structures such as yurts, black tents, defensive structures, and livestock spaces, reflects the social, cultural, and climatic needs of nomads. These structures, in addition to being functional tools for survival and daily life, symbolize the identity and cultural beliefs of the nomads. Documenting and preserving these structures not only helps preserve a cultural heritage but also leads to a deeper understanding of the way of life and culture of nomads.

4. Conclusion

This paper analyzed nomadic architecture as an essential component of the cultural and social identity of nomadic communities. This architecture, which has evolved through continuous interaction with the environment and the use of natural resources, is recognized not only as a temporary shelter but also as a symbol of awareness, adaptability, and resilience in the face of climatic and cultural changes. Classifying nomadic architecture based on functional, spatial-temporal patterns and the biological needs of nomadic communities provides a more precise and comprehensive understanding of this architectural style.

This research, by categorizing nomadic structures into three main groups—movable, semi-movable, and immovable—and identifying various functional patterns such as yurts, livestock spaces, storage areas, recreational spaces, service-commercial spaces, tombs, and defensive structures, illustrates the complexity of nomadic architecture in terms of spatial, climatic, social, and cultural dimensions. Furthermore, these analyses help understand the internal logic of nomadic architecture, laying the foundation for preservation and documentation policies for this invaluable heritage.

In conclusion, it is evident that nomadic architecture is not just a historical cultural heritage but should also be regarded as a living part of contemporary culture, deserving of protection and documentation. By utilizing this indigenous knowledge, sustainable development and nature-friendly architecture can be achieved in today's world. Therefore, protective and research-oriented efforts must be prioritized to preserve this heritage and ensure that the rich identity and culture of nomadic communities are passed on to future generations.

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Unveiling the hidden meanings of transparency: Fondation Cartier's structural reading as an art-cell

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Abstract. In 1994, a globally known luxury goods-manufacturer Cartier collaborated with Jean Nouvel to design a multi-functional building that integrates branding and art in a single space. The architect skeletonized a super-transparent box in Paris with an interlocked structure of glass and steel. By placing transparent and elongated surfaces on facades, Nouvel created real-time changing interplays with ongoing environmental and urban flow. Behind these screens, the transparent mass of the Fondation Cartier melts boundaries between the city and the citizen by providing various spaces for art pieces, exhibitions, installations and besides, working offices. Majorly, the building is valued for its generous opportunities and supportive approach to artists all over the world and, blurs the barriers standing between the artist and the audience by paving visible and accessible ways for everyone. The Fondation Cartier is also identified as an ideological apparatus with its "accessible", "visible" and "honest" structure as a continuation of the comprehensive construction process of Paris called *Grand Projets*. Hence, attentive combination of the modern architectural tendencies, materials and construction techniques are supposed to underline new, light and transparent urban silhouette of the city as a symbolic reflection of the ongoing political agenda. Thus, in this study, it is aimed to unveil the hidden meanings of the Fondation Cartier through semiotic analysis to construct a multilayered perspective on structural and representational stances of the the building which becomes a monumental, light and transparent art-cell in Paris from the mid-1990s until today.

Keywords: Fondation Cartier; Jean Nouvel; Transparent structures; Semiology; Art spaces.

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1. Introduction

Paris has undergone two significant transformation periods since the 19th century. The first urban change occurred in the 1860s when the French Emperor Napoleon III and Georges-Eugene Haussmann agreed that a comprehensive urban transformation was necessary for Paris to prevent riots due to the ongoing discontent between the administrative leaders and the citizens (Fierro, 2003). Thus, Haussmann determined two main principles in the planning strategy of Paris: creating wide boulevards for controllable and visible circulation and decreasing the intensity of mass buildings in the urban context to increase the city's accessibility. Naturally, those superstructural transformations brought about a grand amendment in the infrastructure (Fierro, 2003). This way, the city's wide boulevards provided a safe circulation in urban life, and possible riots and meetings were largely prevented. Compared to the former urban structure of Paris, consisting of narrow streets, the new and lively arteries of the city became concrete representations of a safe urban life. As a result of the grand change in the city, Paris transformed into a vast theater stage where the historical buildings were met with new governmental edifices and housing zones on the two sides of the wide boulevards where the citizens could be easily governed, controlled, and observed.

The second reconstruction period of Paris began during François Miterrand's presidency, and the president initiated a comprehensive regulation program for Paris, called *Grand Projets*, from his selection in 1981. Like Haussmann, Mitterrand aimed to re-create Paris as a commodious city for the citizens. However, as a complementary advantage, Mitterand considerably benefited from the era's modern and improved construction technologies and production techniques. Mitterand's reconstruction process could be summarized as the maintenance of historical artifacts, relocation of existing buildings, and construction of new buildings designed for Paris by the key architects of the time (Fierro, 2003). Thus, *Grand Projets* were conducted by Mitterrand and the architects with a great collaboration of the new materials, especially using glass and steel with the new construction techniques. Musee d'Orsay (1986), Parc de la Villette (1987), Grande Arche la Defense (1989), Louvre Pyramid (1984), Opera Bastille (1989), Ministere des Finances et de l'Economie (1988), Bibliotheque

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Nationale du France (1996), Tjibaou Culturel Centre (2000), and Arab World Institute (1987) were among *Grand Projets* which were designed and built to create a new city silhouette, built environment and urban life for Paris.

Jean Nouvel, the French architect, became a key figure in the grand transformation of Paris during the *Grand Projets.* As a grad student of Ecole des Beaux-Arts, Nouvel's architectural design philosophy is largely fed from the transition of perceptions, visual plays, and multi-layered space concepts. Thus, Nouvel frequently used visual possibilities of glass and steel as light and reflective structural complements (Boissiere, 1996). In his words, "the way of learning should not be based on copying, but on being able to diagnose a specific situation" (Cambert, 2004). Accordingly, the main target of architecture is to respond to people's demands at specific times, and geographies properly comply with Nouvel's design attitude. Thus, architecture is always considered within specific contexts, cultures, climates, and people. Otherside, architects could not easily be freed from facsimile and mechanization. Here, mechanization does not correspond to "mechanics" but to stereotyped designs that ignore personal, cultural, and geographical specificities (Cambert, 2004).

2. An Architectural Reading on Fondation Cartier

Jean Nouvel's attentive design philosophy shows itself in Fondation Cartier pour l'Art Contemporain. Before its design in 1994 by Nouvel, Fondation Cartier was established in 1847 by well-known jewelry manufacturer Cartier S.A (Fierro, 2003). Until a group of investors bought the Cartier in 1972, the brand was located at the Rue de la Paix in the 2nd Arrondissement. In 1984, Alain Dominique Perrin, who collaborated with those investors, founded the art museum with its new name, Fondation Cartier pour l'art Contemporain, to give opportunities to young artists worldwide. In 1994, Fondation Cartier moved its new site to 261 Boulevard Raspail in the 14th Arrondissement of Paris with its new building designed by Jean Nouvel. In accordance with *Grand Projets,* the building's structural characteristics, material usage, and construction novelties reflect the technological improvements of the era, including the use of glass and steel to create 12.000 square feet and a 6-storyed monumental building for the office and art spaces of the Fondation Cartier. The reflective construction materials created a continuously changing urban silhouette of Paris on the surfaces of the building, and the vision is constantly re-produced in accordance with ongoing urban density, climate conditions, and changing daylight. This way, Fondation Carties became one of the city's most outstanding symbolic edifices in the urban context with its complex perception, monumentality, and hidden meanings in design and material choices (Fig.1).

Fig. 1: View of the Fondation Cartier (ArchDaily, 2025)

With its garden penetrating the building and its huge, transparent glass walls on the façade, Fondation Cartier differs from its counterparts by proposing an unconventional exhibition space. Around the glass walls, trees in the garden reach the museum's top and create stunning botanic influences on visitors' perceptions. The Lebanese Cedar, which was planted by French author, politician, and diplomat François-Rene Chateaubriand in 1823, behaves like a gate for the building (Asensio ed., 2002). Also, it determines a symmetry axis in front of the transparent glass façade and contributes to increasing blurred space perception. In this way, Jean Nouvel generates a perception that incites visitors into a transparent and reflective complexity (Baudrillard & Nouvel, 2002). This sort of illusion, which incites curiosity and discovery, strengthens the relationship between the visitor and the building and transforms Fondation Cartier into a living art-cell between perception, reality, reflection, and illusion.

3. Transparency as a Sign for Citizenry / City and Wealth / Honesty
In semiology, a *sign* consists of a signified and a signifier. The sign delivers a specific meaning by substituting and representing a certain entity, philosophy, idea, or object. However, the signified cannot be directly perceived; perceived¸the signifier can easily be conceived (Rifat, 2018). Signs could vary in different circumstances such as a *qualisign* – as a qualitative sign-, *signisign* – as a singular sign – , a *legisin* – as an order sign – , *icon* – as a visual sign –, *index* – as a relative sign – , and a *symbol* – as a compromised representation – (Rifat, 2018). Accordingly, meaning is defined as an entity consisting of certain signals and symbolization methodologies to convey defined information (Preziosi, 1979). From this perspective, the built environment and a city transform into "a bricolage of daily life," which is composed of harmonious signalization and symbolization (Preziosi, 1979). In the architectural discourse, each part of the built environment and architectural products are evaluated as signs to convey a defined language of their era (Kalpaklı, 1990). Accordingly, architectural concepts and the composition of materials could be used in certain methods to convey and symbolize hidden meanings in daily life. Moreover, due to the transparent character of glass, the blurring boundaries between inner and outer spaces were easily produced (Richards, 2006) (Fig.2).

Fig. 2: View of the reflective transparent façade of the Fondation Cartier (Archdaily, 2025)

Transparency is the key concept for the Fondation Cartier, which is achieved by strategically using glass to create a multi-sensory perception of the built environment from history onwards. In the middle of the 13th century, glass was found as a chemical product made of silicon dioxide, which shows liquid characteristics despite its firm and stable quality. Following the 17th century, glass was re-processed into glass-making and glazing technologies, which resulted in a shift in the production industry. Because of its penetrability, cheapness, and ampleness, glass became an important material after its discovery (Wigginton, 2002). Moreover, the spiritual and sacred understanding of glass is also another powerful philosophy that affected the use of glass, especially in Gothic architecture (Richards, 2006). Thus, glass became one of the most prominent architectural materials actively used in structural productions and design philosophy (Elkadi, 2006).

As a novel perspective, Scheerbart proposes that architecture and culture have a reciprocal relationship. Accordingly, more qualified architectural environments can generate a higher level of culture and create a new understanding of design. The material qualities of glass provide a wide range of advantages in the built environment. In this way, the use of daylight could be increased while wide openings were designed in buildings. Moreover, heating and cooling issues could easily be controlled in glass structures to design healthy and livable environments. Additionally, Scheerbart integrates iron skeleton with glass to produce wide openings and high-ceilinged comfortable interiors (Scheerbart, 1972). Thus, special importance is attached to glass and transparency in different fields, such as architecture, painting, and poetry. As a result of glass's material characteristics, transparency became a critical output. Particularly, the Industrial Revolution and developed technological improvements accelerated the application fields of glass, and its transparent and bilateral effects on spatial perceptions became prominent in different design areas (Betsky, 2016). In this way, transparency gave opportunities to glass users, especially architects and space designers, to create extraordinary ambiguities in inside-outside apprehensions and to generate or destroy the boundaries in space (Glass, 2002).

This sort of use shows itself in Fondation Cartier's huge glass walls and trees in the garden. The aggregation of glass walls and the reflective character of the materials create an unclear experiment, and this uncertainty shakes the spatial perception. Novel explains this sensation "… if I look at a tree through the three glass panels, I can never determine if I am looking at the tree through the glass, in front of it, behind it, or the reflection of the tree" (Baudrillard & Nouvel, 2002). With the loss of certainty, the sign becomes an active factor in constructing the building's visual appearance and the perception of its functional units, such as meeting rooms, offices, and exhibition spaces (Fierro, 2003). As Hertzberger defines space, "shaped by what is that surrounds it and otherwise by the objects within it and perceivable by us, at least when there is light… A space is determined as finite and fixed by its periphery and/or the objects in it." However, the glass walls of the Fondation Cartier provide synchronous surveillance both inside and outside (Hertzberger, 2003). Three huge transparent and reflective screens are gathering the city silhouette and the interior of the building as an art-cell in the heart of the city. This telescopic image consists of the Boulevard Raspail, the Place Denfert Rochereau, the Saint-Germain area, and the artworks in one glance (Fierro, 2003) (Fig.3).

Fig. 3: View of the Fondation Cartier (ArchDaily, 2025)

In addition to the bilateral perception of visitors, Parisians can acquire unexpected accessibility to the museum from the streets of Paris. With its huge, transparent façade, Fondation Cartier supports the relationship between artworks and people walking around the street. The reflective and easily seen façades transform the building into a showcase of the city by symbolizing prosperous citizenry in Paris with clarity, accessibility, and visibility. In this way, the building becomes a characteristic piece that gives its character to a city (Rossi, 2006). The artistic performances, installations, and exhibitions pour out Fondation Cartier by composing an art-cell with its legendary garden and reflective, transparent screens. Thus, Fondation Cartier proposes an unlimited design and artistic space in Paris in contrast to the massive and historical edifices of the city (Fig.4).

Fig. 4: View of the Fondation Cartier’s light and transparent façade (ArchDaily, 2025)

In this way, the building became a self-standing art object that continuously changes in accordance with the dynamism of time, sunlight, or climatic alterations of the day. Nouvel values dynamism as an unavoidable and necessary transformation for evidence of vitality (Baudrillard & Nouvel, 2002). Moreover, the exterior of the building and its mass organization lightly contribute to the built environment while reflecting the urban life around the green areas and city sidewalks.

Additionally, glass can be considered a sign of wealth and honesty in the urban context. During *Grand Projets,* Mitterand aimed to show governmental honesty by using transparency with glass-steel structures of the era. Here, in addition to the clarity of the glass, steel signs France's firm and improving stance on a symbolic level. Glass’ symbolic meaning, as a sign, also captivates a “hygienic” perception related to its inner objects. It requires high quality and assurance to show everything without covers or enclosures. It is necessary to be sure about the qualities of products to display them with all their nakedness. A glass of wine must be clear, or a bottle of olive oil must be crystalline to exhibit them in transparent pots. These concepts of prosperity and purity could be defined as semiotic consequences of glass and its transparency. With the transparent facades showing inside with all clarity and revealing the quality of objects inside it, Fondation Cartier glorifies the art.

4. Conclusion

In order to unveil an architectural edifice, it is crucial to understand its representative formations, interpretations, and signs (Kalpaklı, 1990). On the one hand, the site of a building, its urban context, environmental circumstances, design principles, material choices, production technologies, and usage scenarios constitute the overall construction; on the other hand, the hidden meanings of an edifice, the spatial use of the building, the use activity in and out of the structure complete the life story of an artifact. Accordingly, the physical qualities of a building and its perceived meaning play a strategic role in its participation in urban life. Because all factors have been continually changing within the ongoing agenda of the era, the character of an architectural edifice as a sign has also changed in accordance with those changing circumstances. In this way, signs replace the hidden meanings of a phenomenon while unveiling and substituting them. (Erkman Akerson, 2023).

From this perspective, the major transformation periods of Paris are evaluated as critical ruptures in history by bringing out critical changes in the urban context upon signs. Following Haussmann’s reconstruction period, by widening the city's main arteries to increase accessibility, visibility, and safety, Mitterand’s period generated an urban scale symbolization of a prosperous, firm, and honest administration. While each notion is signified by one or more signifiers, a complex and compositional sign appears in the urban context as an architectural edifice specific to this study. Jean Nouvel’s Fondation Cartier is a striking example of the signifier and signified relationship with its transparent and light structure, melting concrete boundaries between the citizen/administration, regular/artistic, and unaccessible/accessible. As Grosz proposes, space is perceived not only by perceptions but also by the body in space itself, which continually enriches with infinite virtual possibilities (Grosz, 2001). The controversial question “does transparency represent real accessibility or not?” Fondation Cartier represents an alternative response to the question of accessibility with these two basic points related to transparency and its signified meanings. The building's huge, transparent glass screens and meaningful garden create a monumental edifice for the city. In this way, Fondation Cartier has been an important interaction space for Parisians, from its first location as a jewelry shop in the 2nd Arrondissement to the present. Nouvel's illusion tactics and complex space perceptions put forward the building as a new spatial concept that can be experimented with ad infinitum by visitors and people who walk around the Paris streets. While the multiple usage supplies a continuous interaction between the city and the art museum, Fondation Cartier is valued as a locus for Paris and its inhabitants by creating a complex interaction space with its transparent characteristics and becoming a living transparent art cell for Paris.

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The relocation and preservation issues of Hasankeyf

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Abstract. Hasankeyf, located in Turkey's Southeastern Anatolia Region along the Tigris River, is a unique cultural heritage site with a history spanning 12,000 years. Due to the Ilısu Dam project, which posed the threat of submerging the area, many significant structures, including the Zeynel Bey Tomb, Artuqid Hamam, Middle Gate, İmam Abdullah Shrine, and Roman-era columns, were relocated to new settlement areas through specialized engineering projects. This effort aimed to preserve historical landmarks but also introduced various challenges, both physical and symbolic.

The displacement of these structures from their original context led to a loss of cultural and historical integrity. This separation disrupted the connection between the sites and their natural and historical surroundings, diminishing their authenticity. Additionally, the relocation process caused damage to some structures, further fueling criticism. Beyond architectural concerns, the Ilısu Dam project had profound socio-economic and environmental consequences. Local communities were displaced, losing their homes, agricultural lands, and centuries of cultural memory rooted in Hasankeyf. Such losses deeply impacted the social fabric of the region.

Environmental repercussions were also significant. The dam's construction altered the local ecosystem, leading to biodiversity loss and the submersion of a unique natural landscape. While the project proponents emphasized economic benefits and energy production potential, the long-term costs to heritage and ecology have been substantial.

The Hasankeyf case highlights the tension between development and heritage preservation. It underscores the necessity of prioritizing in situ conservation and integrating inclusive, long-term planning into such projects to safeguard cultural sites and affected communities.

Keywords: Hasankeyf, Ilısu Dam, cultural heritage, relocation process, preservation

1.Introduction

Hasankeyf is a settlement area located in the Southeastern Anatolia Region of Turkey, stretching along the Tigris River, with a history of 12,000 years, holding significant value as part of humanity's heritage. Throughout history, the region has hosted numerous civilizations, and it has a culturally rich heritage, featuring structures such as cave settlements, bridges, tombs, and palaces that carry the traces of these civilizations.

Despite being declared a natural conservation area in 1981, Hasankeyf faced the risk of submersion due to the implementation of the Ilısu Dam project. According to Çelik (2019), although the dam project is defended on the grounds of offering significant opportunities for energy production and economic development, it has sparked serious debates regarding the preservation of cultural heritage and environmental sustainability.

Although efforts were made to preserve the historical structures in the region by relocating them, this process has been criticized by many experts. The structures that were relocated were physically preserved, but they faced the risk of losing their cultural integrity as they were separated from their original contexts and historical settings. Experts on cultural heritage preservation emphasize that maintaining structures in their original locations is the most effective approach for the sustainability of historical and social memory. However, the relocation process implemented within the Ilısu Dam project did not fully adhere to this principle, and as Demir (2021) states, it has resulted in irreversible changes to Hasankeyf's historical identity.

The construction of the dam is considered one of the key factors threatening the region's historical identity and ecological structure. Specifically, the process of relocating historical structures has sparked various debates regarding the proper way to preserve cultural heritage (Erdoğan, 2018). International organizations such as UNESCO, ICOMOS, and WWF argue that cultural heritage preservation should be carried out on-site. However,

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the challenges of balancing economic development and the preservation of cultural heritage are clearly observed in the case of Hasankey (UNESCO, 2020).

This paper will address the historical and cultural significance of Hasankeyf, discuss the impacts of the Ilısu Dam on the region, and examine the preservation processes, offering alternative solutions. The paper will particularly explore whether the relocated structures have lost their authenticity, the technical details of the relocation process, and the engineering and preservation strategies applied during this process.

2. The Historical and Cultural Heritage Value of Hasankeyf

Hasankeyf is considered one of the oldest settlement areas in Mesopotamia. The region, which bears the traces of numerous civilizations such as the Sumerians, Assyrians, Persians, Romans, Byzantines, Artuqids, and Ottomans, has historically been a key point on trade routes (Fig. 1.). As a result, Hasankeyf has been an important stop not only for its architectural significance but also due to its strategic and economic importance. The region has served as a military, commercial, and religious center at various times, and throughout this process, it has built significant structures while maintaining its cultural diversity. (UNESCO, 2020).

Fig. 1. The Original Site of Hasankeyf

However, with the Ilısu Dam project, Hasankeyf's historical and cultural heritage has been placed under serious threat. While some significant structures in the region have been relocated and preserved, many historical elements have been submerged under the dam's waters. This situation raises the debate regarding the balance between cultural heritage preservation and development projects. (ICOMOS, 2017).

2.1 The Strategic Location and Historical Significance of Hasankeyf

Hasankeyf, due to its location along the Tigris River, has held strategic importance throughout history. Its position on trade routes extending from Mesopotamia to Anatolia has facilitated the region's economic and cultural development. An important settlement since ancient times, Hasankeyf became one of the significant cities of the Islamic world during the Middle Ages. Throughout this historical continuity, Hasankeyf's urban layout has been shaped in harmony with the natural topography and water resources. The castle, city center, and religious structures located along the banks of the Tigris River reflect the region's strategic role in both defense and commerce. Gabriel's (1932) map illustrates the spatial relationships among these structures, forming the historical core of Hasankeyf, shedding light on the physical organization of the city. The map also visualizes the integrated structure of historical buildings with the river, walls, and the urban fabric (Fig. 2).

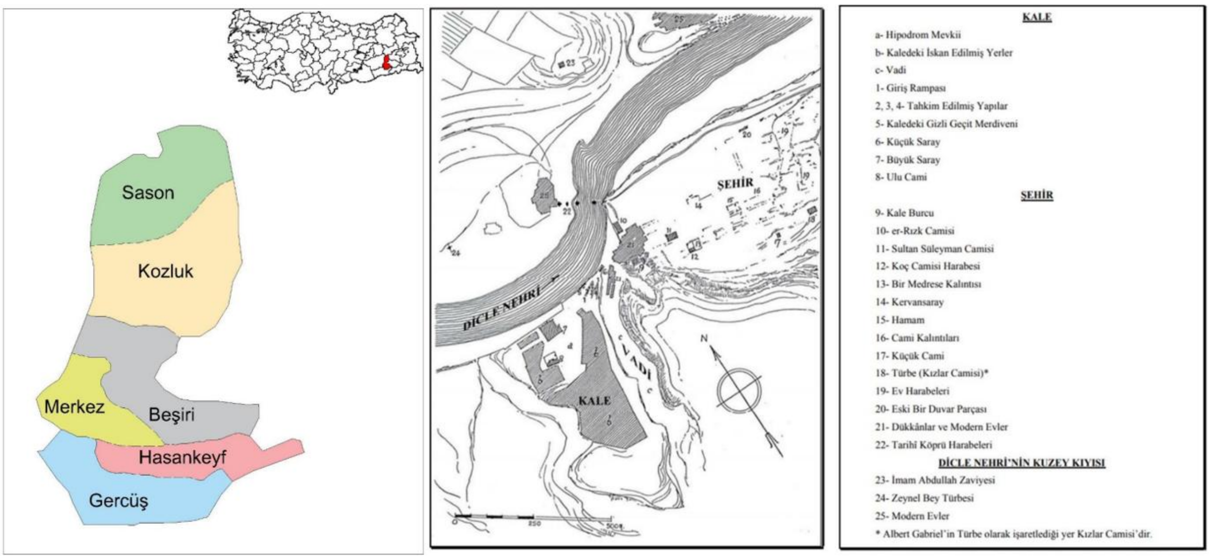

Fig 2.Location and Settlement of Hasankeyf (Gabriel, 1932)

The region's geographical structure, with natural rock formations providing a defensive advantage, led to its use as a "fortress city" throughout history. During the Artuqid and Ottoman periods, this strategic location was also utilized, and the city developed as an important administrative center in the region. During this process, numerous palaces, mosques, bridges, and underground structures were constructed (Atalay, 2021).

2.2 Important Buildings and Architectural Features in Hasankeyf

Located at the crossroads of various civilizations, Hasankeyf has embraced many cultural layers throughout its historical development, resulting in a unique architectural diversity in the region. The structures that span from the ancient period to the Ottoman era are not only significant in terms of historical identity but also stand out for their architectural and engineering features. These buildings serve as important documents reflecting the technical capabilities, aesthetic understanding, and socio-cultural structure of their respective periods. Below, key structures that have emerged throughout Hasankeyf's historical development are presented chronologically, along with their architectural features (Fig. 3).

- Cave Settlements: Hasankeyf contains approximately 6,000 cave dwellings, which were used by different civilizations from the 8th century BC to the Middle Ages. Cave settlements are considered an important part of Hasankeyf's natural and cultural heritage (WWF, 2021).
- Roman Columns and Bridges: Dating back to the 2nd-3rd centuries AD, these structures are key elements that strengthen Hasankeyf's historical context. Particularly, the bridge over the Tigris River highlights the region's importance on ancient trade routes (Zeybek, 2021).
- Castle: Initially constructed during the Byzantine period (4th-5th centuries), Hasankeyf Castle was strengthened by the Artuqids and Ayyubids during the Middle Ages and served as a strategic defensive structure. Its commanding position over the Tigris River provided protection from attacks for many years (UNESCO, 2020).
- Ulu Mosque: Dating back to the 12th century, this mosque belongs to the Artuqid Dynasty and is a significant example of Islamic architecture in the region. The mosque's minaret and interior decorations reflect the development of Islamic art in Anatolia (Yılmaz, 2022).
- Artuqid Bathhouse: This bathhouse from the 12th century is one of the important examples of Artuqid architecture. The bathhouse's original heating and water distribution systems showcase the engineering knowledge of the period (Karahan, 2020).
- Palaces: Numerous palace remains, built from the 13th century during the Artuqid and later Ottoman periods, reflect the region's historical identity. These palaces provide important clues about the administrative structures of the time (Atalay, 2021).
- Zeynel Bey Tomb: Built in 1473 for Zeynel Bey, the ruler of the Akkoyunlu dynasty, this monumental tomb is one of the most recognized structures in the region and carries the influences of Central Asian architecture (Erdoğan, 2018).

Fig 3. Ancient Structures of Hasankeyf (Yılmaz, 2019)

The structures in Hasankeyf have been shaped by the contributions of various civilizations throughout history, resulting in a rich cultural heritage. However, due to dam projects and modernization processes, much of this heritage is now submerged under the reservoir. Although conservation efforts are underway, more comprehensive policies need to be developed to ensure the long-term sustainability of the cultural heritage. Given Hasankeyf's historical and cultural significance, it is essential to adopt more effective conservation strategies at both national and international levels (ICOMOS, 2017).

Hasankeyf has hosted numerous civilizations throughout history, contributing to the accumulation of a rich cultural heritage. However, with the completion of the Ilısu Dam, many significant structures in the region have been largely submerged, and the old settlement area has been drowned. The new settlement area has been built approximately 3 kilometers away from the original settlement, with 710 houses and 98 workplaces completed and handed over to the rightful owners. According to the Ministry of Agriculture and Forestry (2019), efforts to protect the cultural heritage in Hasankeyf are ongoing; as of 2024, volunteers have been encouraged to participate in these activities, and it has been emphasized that this process could create new employment opportunities for the local population through sustainable tourism. Given Hasankeyf's historical and cultural significance, it is evident that more comprehensive and effective strategies for the region's preservation must be implemented at both national and international levels.

3. The Ilısu Dam Project and Its Impacts

The Ilısu Dam is one of Turkey's largest hydroelectric projects, designed to provide economic benefits such as energy production, irrigation, and flood control. However, its impact on cultural and natural heritage has sparked significant debate. The submergence of a historically significant settlement like Hasankeyf under the dam's waters serves as a notable example of the tension between the preservation of cultural heritage and the demands of development. With the completion of the dam, irreversible changes have occurred in the local settlements, ecosystem, and historical structures.

In this context, it becomes evident that the Ilısu Dam is not merely an economic and energy-focused project, but also one that brings about cultural and environmental consequences. Fig. 4 illustrates the overall view of Hasankeyf, most of which has been submerged by the dam's reservoir. In the foreground, the historical settlement area and cave dwellings are visible, while in the background, the transformation of the Tigris River into a reservoir is highlighted. This situation underscores the disconnection of cultural heritage from its natural context and the irreversible spatial changes it has undergone. This section will detail the scope of the project, its effects on physical and cultural heritage, its environmental outcomes, and the socio-economic transformations that have ensued.

Fig 4.The situation after Hasankeyf was flooded by Dam waters

3.1 The Objective and Scope of the Ilısu Dam Project

The Ilısu Dam is a large-scale infrastructure project implemented to enhance Turkey's energy production, improve irrigation systems, and provide flood control. Constructed as part of the Southeastern Anatolia Project (GAP), the dam is situated on the Tigris River and has an annual electricity production capacity of 4.12 billion kWh (DSI, 2020). With the completion of the dam, the objective has been to meet the region's energy demands and accelerate economic development.

However, the construction of the dam has sparked significant debates concerning the preservation of cultural heritage. The risk of flooding historical sites in Hasankeyf and its surrounding areas necessitated various relocation and conservation measures within the scope of the project (Ersoy, 2021). Nonetheless, there are differing opinions regarding the adequacy and impact of these measures. Some experts argue that the relocation of specific historical structures represents a crucial step in protecting cultural heritage, while others contend that this process results in the loss of the structures' original context and disrupts the integrity of the historic fabric. Furthermore, submerging many irreplaceable artifacts is emphasized as a significant loss for the region's historical identity. In addition, criticisms have been raised regarding the conservation efforts, which are confined mainly to physical structures, while the cultural memory of the area and the way of life of the local population have been overlooked. Consequently, ongoing discussions persist within academic circles and the public regarding the long-term effects of the dam on cultural heritage.

3.2 The Effects on Physical and Cultural Heritage

With the construction of the Ilısu Dam, many historical structures in Hasankeyf have been submerged. Although some structures were relocated to new settlement areas using modern engineering techniques, this process has resulted in various physical and cultural changes to the buildings (ICOMOS, 2019). For example, during the relocation process, material loss occurred in some structures, and the buildings were disconnected from their original locations, losing their historical context (Karahan, 2020).

Moreover, cave dwellings and natural rock formations, which are of significant historical and archaeological value in Hasankeyf, could not be preserved and were submerged by the dam waters. These caves, which have been used as living spaces by various civilizations over thousands of years, are among the key structures that reflect the region’s cultural and historical continuity. The natural rock formations, which held not only aesthetic and geological significance but also served practical purposes in the past, such as defense, shelter, and worship, are of considerable importance. However, with the dam’s construction, these unique natural and cultural heritage elements have been irreversibly lost, severely damaging the integrity of Hasankeyf’s historical fabric. This situation is regarded as a significant loss by archaeologists, historians, and environmentalists, highlighting the urgent need for more comprehensive and sustainable measures to protect cultural heritage (UNESCO, 2020).

3.3 Environmental Impacts

The construction of the Ilısu Dam has impacted not only the cultural heritage but also the natural environment of the region. The formation of the reservoir has led to significant changes in the local ecosystem, with the rise in water levels causing damage to agricultural lands and natural habitats (WWF, 2021). Endemic plant species and aquatic ecosystems in particular have been adversely affected by these changes.

Moreover, the dam's water retention capacity has altered the natural flow regime of the rivers, leading to considerable ecological consequences. The changes in the flow rate and discharge of the rivers have negatively impacted the life cycles of many plant and animal species that are dependent on these water sources. Specifically, migration routes of certain fish species have been interrupted, resulting in a decline in their populations and disruptions in the food chain within the ecosystem. In terms of agricultural production, the need to control water levels has forced local farmers to modify their traditional irrigation practices, which has led to fluctuations in crop yields and economic uncertainty. Additionally, changes in soil structure and the effects on the microclimate are posing long-term threats to the region's agricultural potential. The long-term outcomes of these environmental changes are still under investigation, and comprehensive scientific studies are ongoing to fully understand the ecological impacts (Doğan, 2021).

3.4 Socio-Economic Impacts

One of the most significant impacts of the dam project is the socio-economic changes it has caused among the local population. According to UNESCO (2020), thousands of people living in Hasankeyf and surrounding villages were forced to migrate due to the construction of the dam, which resulted in their relocation to new settlement areas. This situation has led to substantial changes in the social and economic structure of the local community.

As noted by Çelik (2022), the displaced population has faced economic difficulties in their new living areas, with communities particularly dependent on agriculture and livestock suffering significant financial losses. According to Yıldırım (2022), the inadequacy of infrastructure and social services in the new settlement areas has negatively affected the quality of life of the local population.

In general, while the Ilısu Dam Project has brought significant benefits in terms of economic development and energy production, it has also sparked considerable debate due to its impacts on cultural and environmental heritage. There is a strong consensus in academic circles and among international organizations that a more balanced approach between the protection of cultural heritage and sustainable development should be adopted (ICOMOS, 2019).

4. The Relocation Process of Historical Structures: Engineering Solutions and Preservation Challenges

The relocation process of historical structures in Hasankeyf is considered a significant example in the preservation of cultural heritage both in Turkey and globally. With the completion of the Ilısu Dam project, many historical structures in Hasankeyf faced the risk of being submerged. As a result, several important buildings were relocated using specialized engineering methods and placed in new conservation areas. However, while this process ensured the physical preservation of the structures, it also caused them to lose their cultural and historical contexts (UNESCO, 2021).

The engineering techniques employed during this process were supported by modern technologies, with the goal of relocating the structures with minimal damage. However, as noted by Ersoy (2021), debates have arisen regarding the detachment of the relocated structures from their original locations and their adaptation to new environments. These discussions have raised the question of whether the preservation of historical buildings should be limited solely to physical relocation or if other aspects of their historical and cultural significance should also be considered.

4.1 Relocated Structures and Applied Engineering Techniques

As part of the Ilısu Dam project, several significant structures were relocated using specialized engineering methods. The relocation process was carried out by various engineering firms under the supervision of the Turkish Ministry of Culture and Tourism. During the relocation, modern engineering techniques were employed, whereby the structures were cut into blocks and transported to new settlement areas (Akgün, 2020). Detailed information on the relocation process of Hasankeyf and the techniques employed is provided below.

The Zeynel Bey Mausoleum: The Zeynel Bey Mausoleum is one of the most notable cultural heritage structures relocated as part of the dam project in Hasankeyf. This monumental structure, weighing approximately 1,100 tons, was transferred to its new location using an integral (monolithic) relocation method. Advanced engineering solutions were implemented to preserve the structural integrity of the mausoleum during the process. First, the connection between the mausoleum and the ground was severed, and steel platforms were placed underneath. These platforms were then gradually lifted using hydraulic jacks. The structure was subsequently integrated into a rail transport system and moved approximately two kilometers to its new location in a controlled manner. Throughout the process, engineering measures such as vibration control, load distribution, and structural stability analysis were meticulously applied to preserve the original structural characteristics and integrity of the mausoleum. The relocation of the Zeynel Bey Mausoleum represents one of the few successful applications of integral transport techniques and reflects the use of modern engineering practices in the preservation of cultural heritage.

Artuklu Bath **:** The relocation of the Artuklu Bathhouse required a different engineering approach. Weighing approximately 150 tons, the structure was dismantled and relocated using a modular relocation method. Initially, architectural and structural analyses of the building were conducted, after which the structure was carefully dismantled into stone blocks. Each block was numbered and mapped to ensure accurate reassembly during the restoration process. High-capacity crane systems and specialized stabilization techniques were employed during the transport, including shock-absorbing cushions and steel support systems to prevent damage to the blocks. This method enabled both the preservation of the building materials and the faithful restoration of the structure at its new location. The relocation of the Artuklu Bathhouse serves as a successful example of the secure relocation of cultural structures using the modular transport method (Fig. 5).

Fig 5. The holistic relocation of the Zeynel Bey Mausoleum and the Artuqid Bathhouse to their new site (CNN Türk, 2018)

Fig 5.Transportation routes of the flooded area and related structures after the Ilısu Dam (medium, 2021)

These relocation processes are of great significance not only from an engineering perspective but also in terms of cultural heritage preservation. Although each structure was moved using different techniques, the overarching objective was to safeguard the historical and cultural value of Hasankeyf without compromising its integrity during the transfer to new locations. The map on the left illustrates the original locations of the Zeynel Bey Mausoleum (in red) and the Artuklu Bath (in blue), while the map on the right depicts their new positions and the routes along which they were relocated. These operations were meticulously planned to ensure the preservation of the structures and the transmission of cultural heritage to the newly established settlement area (Fig. 6).

Eyyubi Mosque Minaret: The minaret of the Eyyubi Mosque was preserved with great care during the relocation process. To prevent any damage during transport, the structure was encased in a steel frame designed to shield it from external forces. The minaret was subsequently lifted and moved to its new location with the aid of a crane. Due to their height and slender construction, such structures pose significant risks during relocation. The steel frame ensured the structural integrity of the minaret, enabling a safe and stable transport process.

Hasankeyf Castle and City Walls**:** Hasankeyf Castle, one of the oldest and most significant structures in the region, presented a particularly complex relocation challenge. Portions of the castle walls were dismantled and reassembled at a new site. However, some of the transported stones suffered damage, and elements of the original structure reportedly lost their authenticity during the reassembly process. Breakage or detachment of stones during transport likely prevented the complete reconstruction of the original form. This highlights a major challenge in cultural heritage preservation: while relocating a historic structure aims to conserve its material presence, such interventions often entail structural and visual compromises.

The relocation of structures in Hasankeyf under the Ilısu Dam project serves as a significant example of heritage preservation through engineering. Historical monuments such as the Zeynel Bey Mausoleum, Artuklu

Bath, Eyyubi Mosque Minaret, and Hasankeyf Castle were relocated using various techniques, drawing on modern engineering solutions. Depending on each structure's specific architectural characteristics, monolithic, modular, or reinforced relocation strategies were employed. Comprehensive planning ensured the protection of structural integrity, the retention of authenticity, and minimal exposure to environmental damage. Nonetheless, certain structures inevitably experienced physical or aesthetic losses during the process. This situation underscores the limitations of engineering in cultural heritage preservation and highlights the sensitivity required in such interventions. Ultimately, the large-scale relocation operations undertaken in Hasankeyf contributed significantly to the physical preservation of cultural assets, but also sparked debates concerning authenticity and the severance of place-based identity. These processes offer a multifaceted experience that must be considered both technically and ethically in future projects of a similar nature. The following section will expand upon this discussion by exploring critiques related to the loss of authenticity and the broader implications of relocation.

4.2 Criticisms of the Relocation Process and the Loss of Authenticity

A significant portion of the criticisms surrounding the relocation efforts emphasize the detachment of these structures from their original historical and cultural contexts, leading to a considerable loss of their spatial and symbolic meanings (Doğan, 2021). These structures are not merely physical entities but are integrally connected to the socio-cultural identity of the region, having been historically embedded within their natural and built environments. In this regard, the relocation process signifies not only a physical displacement but also a transformation of the historical and cultural fabric that these structures embody.

According to Öztürk (2022), there remains uncertainty as to how these relocated monuments will adapt to their new environmental and climatic conditions. Differences in microclimate, soil characteristics, and humidity levels may affect the long-term conservation of the structures, though the extent of such impacts has yet to be fully understood. Therefore, focusing solely on the physical aspects of relocation is insufficient; comprehensive conservation and maintenance strategies must also be developed to ensure the structures' resilience in their new settings.

Yıldırım (2022) argues that the relocation of historic structures results in severance from their original context and cultural significance, as these monuments are not only architectural artifacts but also integral components of collective memory and social identity. Similarly, Şahin (2023) stresses that the relocation of the Zeynel Bey Mausoleum has completely disrupted its spatial and historical relationship with its original surroundings.

Several academic studies have revealed that the relocated structures have, in many cases, been transformed into touristic and economic commodities, often at the expense of their cultural identities (Çelik, 2023). Furthermore, it has been noted that these monuments may become increasingly vulnerable to natural wear and deterioration in their new locations. The long-term environmental impacts of the new settlement areas on the relocated heritage remain uncertain (Şahin, 2023).

In light of these critiques, diverse perspectives within the academic literature reveal that cultural heritage relocation is not merely a technical intervention but a complex and multilayered issue with profound social and cultural implications. Smith (2006) argues that cultural heritage comprises not only physical structures but also the social practices, rituals, and collective memories associated with them. From this perspective, although a monument's physical integrity may be maintained, its contextual and symbolic significance can be severely diminished through relocation.

Similarly, Jokilehto (1999) emphasizes that cultural heritage must be evaluated in a holistic relationship with its spatial context, warning that relocation may disrupt this essential integrity. Research conducted in the Turkish context supports these arguments. For instance, Kaya (2021) contends that although the relocation of Hasankeyf's structures was technically successful, these monuments do not retain the same meaning in their new locations, as their emotional connection with the local community has been significantly weakened.

In this regard, preservation strategies for cultural heritage should not be limited to the technical aspects of relocation but must also incorporate comprehensive approaches that consider historical context, local identity, and collective memory. While the relocation process implemented in Hasankeyf involved noteworthy engineering solutions for heritage protection, it has largely remained confined to physical preservation, failing to fully address the contextual values of the cultural assets. Although the structures continue to exist in material form, the relocation has not ensured the preservation of their authenticity and historical identity.

Therefore, future projects of a similar nature must include more holistic planning that safeguards the historical and cultural contexts of relocated structures. Additionally, to ensure the long-term sustainability of the relocated monuments, the development of regular monitoring and maintenance programs is essential.

5. Conclusion and Recommendations

Although the cultural heritage relocation process carried out in Hasankeyf is considered a significant achievement in terms of technical and engineering aspects, the cultural, historical, and sociological dimensions of this process should also be addressed comprehensively. Iconic structures such as the Zeynel Bey Mausoleum, the Artuklu Bath, and the Minaret of the Eyyubi Mosque have been relocated to new areas with their physical integrity preserved; however, this relocation has led to the disconnection of these structures from their historical context. These structures derive their meaning not only from their architectural features but also from the landscape in which they were situated, their social environment, and their past functions. Therefore, the relocation process represents a physical transfer and a transformation of spatial memory, identity values, and collective meaning.

The preservation of cultural heritage, as emphasized by international organizations such as UNESCO and ICOMOS, is possible not only through the sustainability of the physical existence of the structure but also through the continuity of its original context, social functions, and societal relationships. In this context, the process carried out in Hasankeyf has brought ethical and methodological debates concerning cultural heritage preservation to the forefront beyond the engineering achievements. Indeed, the relocated structures cannot fully sustain their meaning in the new settlement areas, and their historical ties with the local community are weakening. This demonstrates that it is not sufficient to reduce cultural values to their material characteristics alone; cultural heritage's social and symbolic aspects must also be preserved.With the advancement of technology, methods such as digital archiving, 3D modeling, and virtual reality have become increasingly important in preserving cultural heritage. Especially for assets that cannot be relocated or are at risk of destruction, documentation in digital environments will enable their future use for academic and cultural purposes. As in the case of Hasankeyf, such digital documentation projects play a significant role in preserving the lost original context and historical value of relocated structures. The reconstruction of these structures in virtual environments and their presentation to the public through interactive displays can help cultural heritage reach broader audiences. In this regard, it is necessary to increase digital documentation projects for the preservation of Hasankeyf and to raise public awareness of these processes. In addition, the participation of the local community in the preservation of cultural heritage is of great importance. The exclusion of the local population from the relocation process jeopardizes the sustainability of preservation policies. As UNESCO emphasizes, the active participation of local communities in these processes is a critical factor for maintaining and embracing cultural heritage. In this framework, developing sustainable development models for Hasankeyf and supporting cultural tourism projects will strengthen the regional economy and encourage the local population to take ownership of the cultural heritage.

On the other hand, adapting relocated structures to new environmental conditions is another issue that must be carefully monitored in the long term. Environmental factors such as different soil types, humidity levels, and microclimatic effects may negatively impact the relocated buildings' structural integrity. This situation indicates that the physical relocation and subsequent protection, monitoring, and maintenance processes should be conducted with a comprehensive and sustainable strategy. For long-term success, the physical integrity of relocated structures must be preserved along with their cultural contexts and connections to social memory.

Many academic studies highlight that the relocation process not only aims to preserve the structures but also transforms them into touristic elements and economic commodities in their new settlement areas. This indicates that the understanding of cultural heritage preservation is increasingly acquiring a commercial dimension. Furthermore, it is stated that the environmental and climatic conditions the relocated structures will face—particularly factors such as differences in soil, humidity levels, and microclimate effects—create uncertainties regarding their long-term durability. The discussions in academic literature suggest that cultural assets cannot be preserved through engineering interventions alone and that holistic preservation strategies enabling adaptation to their new locations must be developed. When separated from their natural and social environments, these structures experience significant losses not only in physical terms but also in symbolic and cultural contexts.

The transformation experienced in Hasankeyf emphasizes that technical solutions alone are insufficient in cultural heritage preservation and that historical structures must be addressed holistically within their environmental, cultural, and social contexts. Although modern tools such as engineering techniques and digital documentation are essential for preserving structural integrity, the process should not be limited to the physical relocation and recording of the structures. Historical buildings are deeply connected with the cultural and socio-economic structures of the geography in which they are located. In this context, relocated structures should be preserved not only through construction techniques but also through the social memories, cultural identities, and relationships with the local population inherited from the past. The exclusion of the displaced community from the relocation process may result in the loss of the social and cultural contexts of cultural heritage. It may also have long-term negative impacts on its sustainability. The preservation of cultural heritage requires a multidimensional approach that encompasses not only the physical structures but also the surrounding natural and social environment. As in the case of Hasankeyf, the adaptation of relocated structures to their new environments, considering environmental factors (microclimate, soil conditions, humidity levels) and social structures, will ensure the sustainability of not only the physical but also the cultural values of this heritage. Therefore, the participation of the local population in the preservation of cultural heritage is of great importance; the community's sense of ownership and belonging contributes to the conservation of social memory and regional history. The preservation process implemented in Hasankeyf reveals the necessity of a multidisciplinary approach that considers the relocated buildings' structural features and their social contexts.

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Conservation assessment of historical healthcare facilities: An investigation of Cebeci Hospital in Ankara University Faculty of Medicine

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Abstract. Ankara University Faculty of Medicine is a significant institution in Türkiye's medical education history, reflecting the modernization efforts of the early Republican period. Established under Mustafa Kemal Atatürk's directive, the faculty played a key role in shaping the country's healthcare system. Constructed during the First National Architectural Movement, its architectural character reflects the era's emphasis on national identity, functionality, and the use of local materials. However, during the last decades, for the sake of responding to the modern needs in healthcare buildings, new annexes have been added to the hospital.
This study examines the architectural changes the faculty went through over time. It does so by analyzing the architectural features of the different building blocks, new and old, Cebeci Hospital in Ankara University Faculty of Medicine. Hospitals, beyond their medical function, represent institutional trust, state authority, and the accessibility of public health services in the architectural language of their time. The case study-based assessment of the historical building conservation showed that while initial structures are aligned with the principles of the First National Architectural Movement, later structures reflected modifications that impacted the historical integrity. The research highlights the need for future recommendations for adapting contemporary healthcare needs to the heritage conservation strategy of the hospital complex.

Keywords: republican architecture; healthcare architecture; built heritage conservation; Turkish National Architecure

1. Introduction

Ankara University Faculty of Medicine is one of the most historically and culturally significant institutions where the foundations of modern medical education in the Republic of Türkiye were established. Examining and understanding this meaningful structure, which holds great importance in the country's history is critical for comprehending the development of healthcare buildings during the early Republican era. Beyond their medical function, hospitals represent institutional trust, state authority, and the accessibility to public health services.

Public buildings constructed for healthcare purposes during the initial years of the Republic reflect the characteristics of the First National Architectural Movement. In the capital city of Ankara, ministerial buildings serve as symbolic structures representing political authority (Gürdağ & Koca, 2020). From this perspective, the building can be considered a bridge connecting the past to the future, serving as a significant vessel of memory for understanding the period, which constitutes the central focus of this study.

This article aims to evaluate the architectural period of the building and associate it with the characteristics of Ankara University, Faculty of Medicine, Cebeci Hospital. Rather than treating the building merely as an architectural work, the study seeks to align the building with the history of the Republic and interpret it as a culutural heritage asset. Furthermore, this investigation aims to highlight the contributions of the biulding to the modernization of healthcare buildings in the Republic of Türkiye. In this context, by analyzing the transformations and additions the building has undergone since its establishment, the study aspires to contribute to the preservation of Turkish historical and cultural h.eritage and ensure its transmission to future generations. Despite the significant role of Cebeci Campus in the formation of modern medical infrastructure in Türkiye, its architectural transformations have not been extensively documented. This paper addresses this gap by offering an analytical perspective on its spatial evolution and conservation needs.

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2. The First Turkish National Architectural Movement and Ankara University Faculty of Medicine

The building of Ankara University Faculty of Medicine reflects the features of historical educational and healthcare institutions from the Ottoman period such as *Darülfünun* and *Darüşşifa*. The history of the Faculty extends back to the foundation of the Republic. The Cebeci Research and Practice Hospital is the first hospital of the first Faculty of Medicine established under the directive of Mustafa Kemal Atatürk during the early years of the Republic (Arda, 1996).

Influenced by Islamic civilization, the Turks combined the Arabic term *"dār al"*, meaning "house," with *"shifā"*, meaning "healing" or "recovery," to name public health structures *"Darüşşifa"*. The purpose ıs to indicate buildings that provided healthcare services to the community. During the Ottoman period, there were numerous *Darüşşifa* buildings established to offer free medical services to the public (Umar & Sarı, 2020). These institutions also played significant roles in the provision of healthcare services in Ankara. However, during the Independence War, these structures became insufficient, leading to the adoption of provisional solutions. The establishment of Ankara University Faculty of Medicine was a response to the growing awareness of such deficiencies and a part of the modernization efforts carried out during the Republican era, aimed at providing contemporary medical education and healthcare services (Arda, 1996).

Although the Faculty's foundations were influenced by the Ottoman health system, it is evident that its establishment faced shortcomings imposed by the needs of the pre-Republican period. Ankara University Faculty of Medicine holds a special place in the history of medicine in Türkiye as a pioneering institution in laying the foundations of the Republic's modern healthcare and medical education system. Due to its historical and national significance, the Cebeci Hospital (Fig. 1. & Fig. 2.) is considered a "Veteran Hospital (*Gazi Hastane*)." The Chief Physician's building and the U-shaped campus behind it were designated as a "Preservation Area" in 2005 by the Ankara Regional Board for the Conservation of Cultural and Natural Assets under the Ministry of Culture and Tourism (AKVMGM).

Fig. 1. Ankara Medical Faculty Cebeci Campus, URL1, 2012

Fig. 2. Ankara Medical Faculty Cebeci Campus, URL1, 2000

2.1. Architectural Characteristics of Ankara University Faculty of Medicine and Its Relationship with the First National Architectural Movement

The First National Architectural Movement of the Republican Period coincides with the early phases of Türkiye's modernization process. Led by architects Kemaleddin and Vedat Tek, this movement was referred to by

Kemaleddin himself as the "National Architecture" (*Milli Mimari*) and was defined as follows: "This movement is similar to the Neoclassical movement in Europe. It features works that combine the forms of Classical Ottoman architecture with new interpretations. It incorporates the forms and styles of the Ottoman Classical period and bears traces of the transitional era. It was inevitably influenced by Western architecture" (Çaha, 2022).
In the early years of the Republic, an approach that blended national architectural elements with modern styles was adopted. Unique examples of Turkish Neoclassicism were produced during this period (Kızıldere & Sözen, 2005,). Significant contributions to the movement were also made by Ahmet Hikmet Bey (Koyunoğlu) and the Italian-born architect Giulio Mongeri (Hasol, 2017).

Compared to previous periods, the architecture of this era was much simpler and more minimalist. Functionalism was prioritized, and buildings emphasized practicality and usability. Structures built during this time were more modern and Western-oriented than other Ottoman-era buildings within the country's borders (Kızıldere & Sözen, 2005). Simple forms were employed, and there was a tendency toward geometric shapes. The emphasis was placed on highlighting national architecture, and particular attention was given to the use of local materials and regional products (Bozdoğan, 2003).

The buildings constructed during this time of social transformation were especially prominent in the healthcare, public, and educational sectors. In this context, the Second Turkish Grand National Assembly (II. TBMM) (Fig. 3.) Museum and Ankara Palas (Ankara Vakıf Hotel) (Fig. 4.), which are located in front of each other, are considered exemplary buildings from this era. Ankara Palas, in particular, is one of the best representations of the period with its symmetrical plan aligned along the entrance axis, wide eaves, dome, and tile cladding (Hasol, 2017).

Fig. 3. Second Grand National Assembly Building, URL2, 2021

Fig. 4. Ankara Palas, URL2, 2021

Ankara University Faculty of Medicine was built during the First National Architectural Movement of the Republican Era. Buildings from this architectural period are known for reflecting the national identity of the Republic of Türkiye and frequently incorporating local elements (Fig. 5.) (Çubukçu, 2021).

The architectural design of Ankara University Faculty of Medicine (Fig. 6. and Fig. 7.) also reflects the principles of this national architectural movement. The building was designed and constructed in accordance with the stylistic features of the First National Architecture. Local elements were included in the design process, and the use of local materials was prioritized. The incorporation of native stone and natural building materials is a direct reflection of the architectural approach of this period. The building features design elements that reflect Turkish national identity and emphasize national values. It is significant lies at its contribution to Türkiye's struggle for independence and the strengthening of national consciousness.

Fig. 5. Cebeci Campus Entrance Wall – Ankara Stone Usage (Source: the author, 2024)

Fig. 6. Ankara Medical Cebeci Hospital, URL1, 1950

Fig. 7. Ankara Medical Cebeci Hospital, URL1, 2013

3. Evolution of the Building's Changes Overtime

The campus was established in 1945 and has served as the main building of the Faculty of Medicine since ever. It covers an area of 70 acres and stands out with its location close to the city center. In addition to the Faculty of Medicine, the campus also houses various research units, laboratories, a library, and student accommodation facilities (URL1, 2023) (Fig. 8.).

Fig. 8. Location of Ankara University Campuses, URL1, 2023

The Cebeci Campus takes its historical significance from the function of healthcare facility it served during the Turkish War of Independence. Backthen, the building was used as a cavalry barracks. The threat of World War II led to the adoption of various precautionary measures and policy reviews in Türkiye. In this context, due to the risk of Türkiye entering the war, it was decided to relocate the Gülhane Military Hospital from Istanbul to Ankara. While Cebeci Hospital was established in 1941, it began to operate in 1945 as the first Faculty of Medicine of the Republic of Türkiye. In 1953, by the decision of the Ministry of National Defense, the Cebeci Buildings were prepared and officially transferred to the Faculty of Medicine. This developmental process continued with the opening of İbni Sina Hospital in 1985 and the establishment of specialized clinics within the General Surgery Building. Alongside modernization and increasing medical infrastructure, the Surgery Building was reinforced and the laboratory facilities were improved (URL1, 2023).

The primary reason for the additions and modifications made to the Faculty was the growing demand for medical education and the need for modernization. Since the hospital was initially designed for military purposes, the post-war transformation into a center focused on medical education and necessitated the construction of new buildings. The relocation of clinics from Numune Hospital to the Cebeci Campus allowed for a more efficient use of space. The modernization objective was to integrate technological advancements and to make the physical structure more effective for both medical education and healthcare services. During the restoration period from the 1970s to the 1990s, the use of older clinics was altered, and the U-Block began to host various medical departments. Restoration and renovations during this period aimed to create a more compatible working environment having contemporary healthcare standards (URL1, 2024).

With its rich history, the building has become one of the symbols of modern medicine and stands as a prominent emblem of Ankara University Faculty of Medicine in the centennial year of the Republic. The architectural evolution of the campus may also be interpreted as a reflection of the continuing advancements in the field of medicine to the present day (URL1, 2024).

4. Preserved and Preservable Sections

The Cebeci Campus is notable for its U-shaped layout (Fig. 9.). This architectural form accommodates recreational spaces at its center, offering ample green areas for visitors. Similar U-shaped structures can also be observed in other parts of the campus. These configurations are creating spaces for social interaction and recreation in the campus (Fig. 10.).

Fig. 9. Gynecology Department Block (Source: the author, 2024)

Fig. 10. Rectorate Resting Area, P.A. (Source: the author, 2024)

During the construction of the campus, particular emphasis was given to the use of local materials, and it has been identified that andesite stone—commonly known as Ankara Stone (Fig. 11.) —was frequently utilized. The ornamental elements used in the window details and the prominent red color aimed at emphasizing the architectural characteristics of the buildings (Fig. 12.).

Fig. 11. Use of Ankara Stone (Source: the author, 2024)

Fig. 12. Blood Center (Source: the author, 2024)

In addition, sculptures with symbolic meanings are located at various points throughout the campus. For example, the sculptures featuring Angora goats (Fig. 13.) reference the historical heritage of Ankara, while the statue of a pregnant woman (Fig. 14.) placed in front of the maternity hospital symbolizes birth. These sculptures are intentionally positioned to better reflect the cultural value and historical significance of the original structure.

Fig. 13. Angora Goats Sculptures (Source: the author, 2024)

Fig. 14. Sculpture Titled Dressing (Source: the author, 2024)

Design of entrance in the campus building shows noticeable differences. In addition to the entrances constructed as part of the original structure, there are also modern entrances added in later periods. The use of metal and glass materials (Fig. 15.) reflects these temporal modifications and emphasizes the architectural transformation over time. However, renovations carried out over the years—particularly the installation of air conditioning units and exposed piping (Fig. 16.) —have caused significant damage and led to a loss of aesthetic value in the building's original design.

Fig. 15. Oncology Building Entrance (Source: the author, 2024)

Fig. 16. Radiotherapy Outpatient Clinic (Source: the author, 2024)

Over time, additional buildings have been constructed within the campus to support the growing needs of the hospital. One such example is the "Pediatric Emergency" building. By utilizing facade materials similar to Ankara Stone, efforts were made to ensure architectural coherence with the overall identity of the campus. The use of colored glass on the exterior was intended to evoke a link to children (Fig. 17.). A similar design approach can also be observed in the Gastroenterology Building (Fig. 18.).

Fig. 17. Pediatric Hospital Perspective (Source: the author, 2024)

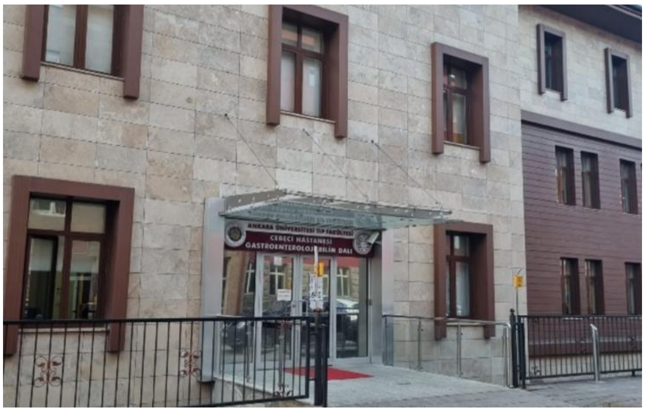

Fig. 18. Gastroenterology Outpatient Clinic (Source: the author, 2024)

However, not every additional building has been constructed in harmony with the historical character of the campus. Structures such as the security post, cafeteria, and childcare center (Fig. 19.) —located near the main entrance—were added later. They, however, failed to reflect the historical architecture due to their material choices. Similarly, the Faculty Dining Hall Building (Fig. 20.), which houses banking and dining facilities, also diverges from the campus's historical texture due to its use of incompatible materials.

Fig. 19. Security and Cafeteria Area (Source: the author, 2024)

Fig. 20. Faculty Dining Hall (Source: the author, 2024)

5. Conclusions

This study examined the architectural structure of Ankara University Faculty of Medicine and aimed to highlight its significant place in the history of medicine in Türkiye by reflecting the characteristics of the First National Architectural Movement of the Republican Era. It was determined that the changes and additions made to the building were intended to meet the increasing demands of medical education and healthcare services. The preserved and preservable sections of the Cebeci Campus represent a rich cultural heritage, enriched by the use of local materials and symbolic sculptures.

However, it has been observed that the modern entrances and buildings added later have compromised the aesthetic integrity of the original structure. While preserving the historical character of this significant site is crucial, these additions have been inadequate in maintaining the integrity. Future restoration efforts should prioritize the architectural coherence between old and new structures, ensuring that new additions do not compromise the symbolic and historical integrity of the original building.

This study was conducted with the aim to understand the architectural evolution of Ankara University Faculty of Medicine and supporting efforts for its conservation. The preservation of the Cebeci Campus is not merely about maintaining individual buildings, but it is also about sustaining a tangible legacy of Türkiye's medical and architectural modernization. This legacy holds educational, cultural, and symbolic value. As such, conservation strategies must be informed by a long-term vision—one that balances healthcare innovation with historical responsibility. By respecting, both the past and the present, the Cebeci Campus should continue to serve as a meaningful and functional heritage space for future generations.

Acknowledgments

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Comparison of wooden masonry (çantı) technical mosques in near geographies: Georgia Adjara Region and Trabzon rural architecture

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Abstract. Wooden masonry mosques in Turkey, especially in the Black Sea Region, are under the threat of extinction due to reasons such as the disappearance/degradation of wood, inadequacy of construction artisans, and natural disasters. It is also possible to see examples of mosques built with this technique in geographies close to the Black Sea Region. Georgia, whose mosque architecture was shaped by the adoption of Islam during the Ottoman period, and the rural architecture of Trabzon in the Eastern Black Sea Region are two prominent regions with wooden mosques with unique values. Especially in Georgia and the Black Sea Region, centuries of cultural exchange and architectural and artistic style interaction have led to the emergence of similarities and differences in the mosque architecture of the regions (plan schemes, materials, construction techniques, etc.). In this study, the primary mosque structures built with the wooden masonry technique in the Adjara Region of Georgia and Trabzon countryside were evaluated in terms of the construction system, material properties, and plan schemes by analyzing the qualitative data obtained as a result of literature reviews. The similarities and differences of the mosques selected within the scope of the study have been examined, and their comparative analyses have been made by analyzing them vectorially. Although some architectural solutions in close geographies are similar to each other, cultural and regional differences and the necessity of building appropriate to the region have increased the architectural diversity of both regions.

Keywords: Wood Masonry; Construction System; Mosque; Georgia; Trabzon

1. Introduction

Wooden mosques stand out as important architectural works of art in our country, especially in the Black Sea Region. With the architectural style specific to the region, construction techniques based on master-apprentice relationships, and the use of local materials, original examples of wooden mosques have survived to the present day. Wooden mosques built according to the nature of the region and local traditions may show different characteristics depending on the diversity offered by the Black Sea geography.

The wooden mosques in the region have survived to this day as a reflection of a culture that has lasted for centuries. While mosques made entirely of wood are frequently seen around Samsun and Ordu, wooden masonry (çantı/çandı) mosques are mainly dated to the 18th and 19th centuries in the central and eastern parts of the Black Sea Region (Zorlu, 2017).

The studies on wooden masonry mosques in different provinces of the Black Sea Region have dealt with detailed documentation, structural and spatial analysis, ornamental features, and typological analyses. These studies analyzed the mosques on a single-building scale or specific to a particular region. At the same time, there is also a study in the literature on determining the risks arising from nature and using wooden masonry mosques (Yücel, 2022).

In the city of Trabzon and its districts, which reflect the unique nature of the Eastern Black Sea region, it is possible to come across the wooden masonry technique mosques mentioned in the present study (Karpuz, 1990). In this study, the structural and architectural features of these mosques, which have become an important part of rural architecture and wooden architecture and have survived to the present day with the repairs and restoration works, will be examined through the data obtained from the literature and archives. The study included Uzungöl Filak Mosque, Güney (Kondu) Neighborhood Mosque, Dereyurt Village Merkez Eski Mosque, Masele Mosque, Kuşluca Mosque and Taşkıran Neighborhood Mosque.

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The architectural style of the Eastern Black Sea wooden masonry mosques continues in the Adjara Region of Georgia in the nearby geography. Especially during Ottoman rule, the increase in Islam in the region allowed the increase in the number of mosques in the countryside and the use of construction techniques learned due to cultural interaction in the construction of mosques. In this context, the wooden masonry mosques of the rural Trabzon and Adjara Region were examined in detail in terms of architectural plan, structural features, materials, and construction system. It aims to reveal the architectural and artistic values by determining the similar and different aspects of the mosques with original woodwork through the selected examples. The study utilized information obtained from literature, architectural drawings taken from the archive of the Trabzon Foundations Regional Directorate (TVBM), inventory studies, and photographs determined within the scope of the Eastern Black Sea Project (DOKAP).

2. Wooden Masonry (Çantı) Technique Mosques in Trabzon

Wooden mosques have an important position in the historical development of Turkish architecture. The first known examples of wooden mosques in Central Asia can be seen in cities such as Samarkand and Bukhara during the Ghaznavid and Qarakhanid periods. In Anatolia, Sivrihisar and Afyon mosques dating to the 13th-14th centuries, Ankara Arslanhane and Beyşehir Eşrefoğlu Mosques are the surviving wooden mosques (Karpuz, 1989).

Looking at the general characteristics of the wooden mosques in the Eastern Black Sea region, most of them are located on a sloping terrain. Stone material was used in the subbasement to protect the wood from excessive rainfall. In single-story mosques, stone walls rise to the entrance level, while in two or three-story mosques, the upper floors are built as wooden masonry or carcass.

According to Ayverdi (1972), wooden çandı or çantı structures were constructed by joining long logs together without nails (Ayverdi, 1972). The skeleton of the wooden masonry system consists of horizontal and vertical bearing trees. The wooden masonry walls between the carriers are generally made of 4-5 cm thick chestnut and yellow pine trees (Karpuz, 1989). The boards placed on top of each other are joined in different ways. Different names are used for corner joints depending on whether they are round or rectangular (Fig. 1). In the mosques of the region, the kurtboğaz technique is mostly preferred. (Fig. 2). In cases where the length of the window and door edges and the wooden element was not sufficient, poles called armoz were placed in the middle of the walls. The number of channels opened to these posts varies according to the place of use (Fig. 3).

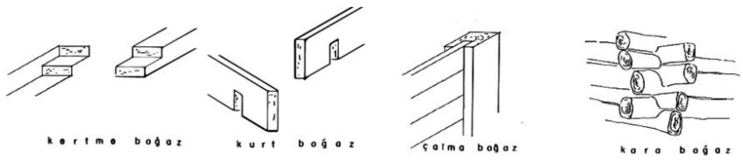

Fig. 1. Types of wooden masonry throat joints (Özgüner, 1970)

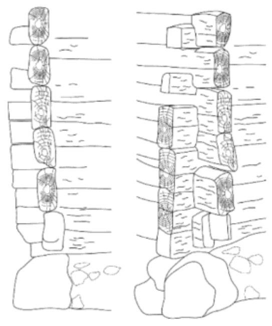

Fig. 2. Drawing of rectangular section kurtboğaz technique (Halı Kabataş ve Sağıroğlu, 2021)

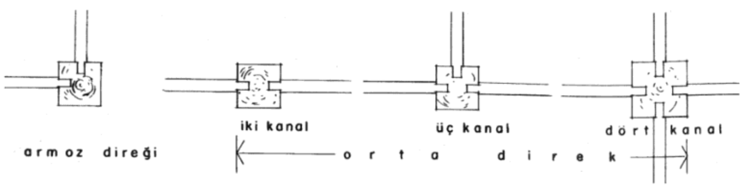

Fig. 3. Armoz pole and center pole connection types (Özgüner, 1970)

In this part of the study, six mosques of Trabzon built with wooden masonry technique were examined, and their spatial characteristics, materials, and construction techniques were typologically analyzed in the light of literature reviews and information obtained from the Trabzon Regional Directorate of Foundations.

2.1. Çaykara, Uzungöl Yeni Neighborhood, Uzungöl Filak Mosque (1813/1819)

Filak Mosque is located in the center of Filak Neighborhood, which is within the borders of Uzungöl Yeni Neighborhood of Çaykara. There is a distance of 2 km from Uzungöl. The construction date of the mosque is known as Hijri 1235, Miladi 1819 (Aydın & Perker, 2017).

The mosque consists of three floors: basement, harim, and mahfil floor. The entrance to the building, which is located on a sloping land in the north-south direction, is provided from the north façade. While there is direct access to the harim from the last congregation, the mahfil floor is reached by stairs. The harim is entered through a door made of walnut wood with two wings. The mahfil floor has a U-plan at the entrance and is carried by wooden pillars (Karpuz, 1990).

The building was constructed using the wooden masonry technique and was over two floors. While the walls of the north, south, and east façades of the basement floor are stone walls, the wall of the west façade was built with the göz dolma technique. The thickness of the stone walls varies between 70-80 cm. Wooden masonry technique is seen at the corner points of the walls surrounding the harim. The timbers with rectangular sections ranging between 6-8 cm are joined at the corners with the kurtboğaz technique.

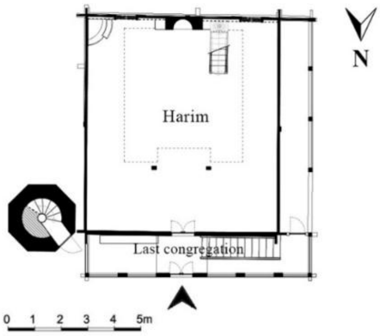

Fig. 4. Uzungöl Filak Mosque (Drawing: TVBM; Url 1)

2.2. Dernekpazarı, Güney (Kondu) Neighborhood Mosque (1819)

Dernekpazarı is located on the Çaykara-Of highway after crossing the Soğanlı Mountains that separate Anatolia and the Eastern Black Sea. The mosque is located on a sloping terrain on the steep slopes of the Güney (Kondu) neighborhood of the Dernekpazarı district. According to written sources, the mosque dates back to 1819. Gregorian terms correspond to 1883-84 (İren, 1983).

The mosque has three floors: basement, harim, and mahfil floor. There is a two-storey madrasah to the south. Due to the fact that the land where the building is located is quite sloping, the entrance to the harim is provided from the west façade. Therefore, the location of the last congregation is also in the west direction. Measuring 8.5 x 8.62 m, the entrance to the square harim is provided by a double-winged wooden entrance door. Wooden stairs from the harim lead to the U-planned mahfil floor. A separate entrance to the mahfil is given from the closed area above the last congregation from the north façade (Çalık and Konak, 2021).

Due to the sloping terrain, the basement floor is also under the ground except for the south façade of the basement floor, which was built with masonry rubble stone with a thickness of approximately 1 m (TVBM, 2019). The walls of the harim floor were built with a wooden masonry system using the kurtboğaz technique at the corners. Centre posts were placed between the wall system from the beginning of the ground floor to the mahfil floor. In this system, called çalma boğaz, in cases where the wood's length is insufficient, there is a wall mesh that is extended by passing it to the intermediate pillar elements. Another construction system seen in the mosque is found on the upper floor of the last congregation place with a few overhangs carried by wooden poles. The entire south façade and more than half of the west façade of this overhang were constructed with the muskalı dolma technique.

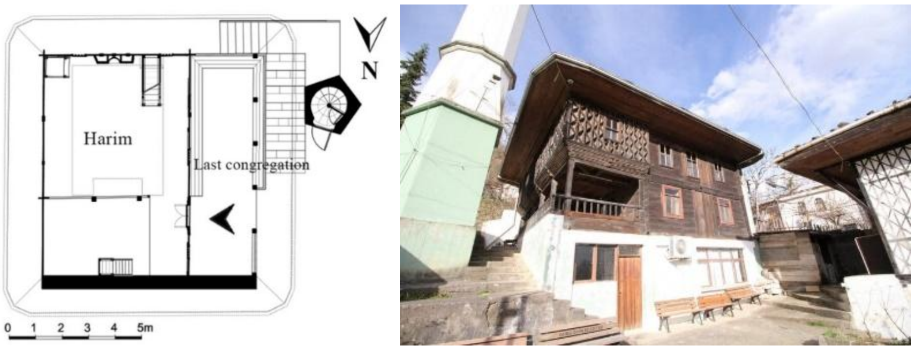

Fig. 5. Güney (Kondu) Neighborhood Mosque (Drawing: TVBM; Url 2)

2.3. Hayrat, Dereyurt Village, Merkez Eski Mosque (1832)

Dereyurt village is located 3 km from the center of the Hayrat district of Trabzon. The Merkez Eski Mosque is located in the central position within the sloping land of the village. The construction date of the mosque dates back to 1832-33 in Gregorian (Yıldırım, 2016).

The mosque was built with two floors, the harim and the mahfil floor. It has a seating area of approximately 10 x 9.6 m and is close to the square (TVBM). The entrance to the harim floor of the building is provided by a two-winged wooden door with round arches from the west façade. Both the harim and the imam rooms adjacent to the north wall of the harim are reached by the last congregation. Wooden stairs access the mahfil floor above the imam's room in the north-east of the harim. When the construction system of the mosque was analyzed, a wooden masonry system was used throughout the floors. The corners of the building were joined with the kurtboğaz technique, and intermediate pillars were placed along the wall system, especially on the sides of the window and door openings.

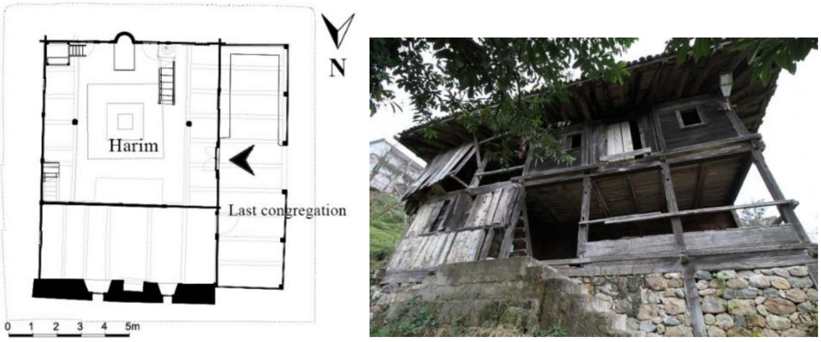

Fig. 6. Merkez Eski Mosque (Drawing: TVBM; Url 3)

2.4. Araklı, Bereketli Village, Masele Mosque (1867)

Masele Mosque is located in Bereketli village of Araklı district of Trabzon. According to the inscriptions on the building, it was built in H.1283 / M.1867. The mosque, which was known as 'Mesele Mosque' among the people because the people of the neighborhood solved their problems in the mosque, was later recorded as 'Masele Mosque' (Sarı, 2021).

The mosque was built on a single storey, including the harim floor, on a sloping land on a stone foundation up to the subasman level (Önal and Köşklü, 2020). The harim measures 5.60 x 6.36 m internally and is close to a rectangular form. The last congregation place and the imam's room are placed side by side to the north of the harim. The entrance to the harim is provided by a wooden door with round arches and a single wing from the last congregation. The building was rebuilt in its present location with the materials salvaged as a result of a fire (Sarı, 2021). The fact that it was built with a wooden masonry technique makes it possible to dismantle these mosques and move them from one place to another. The corner points of the harim, the last congregation place, and the imam's room were joined with the kurtboğaz technique. Intermediate pillars were placed on the window edges and the sides of the mihrab in sections varying between 10x15/10x20 cm.

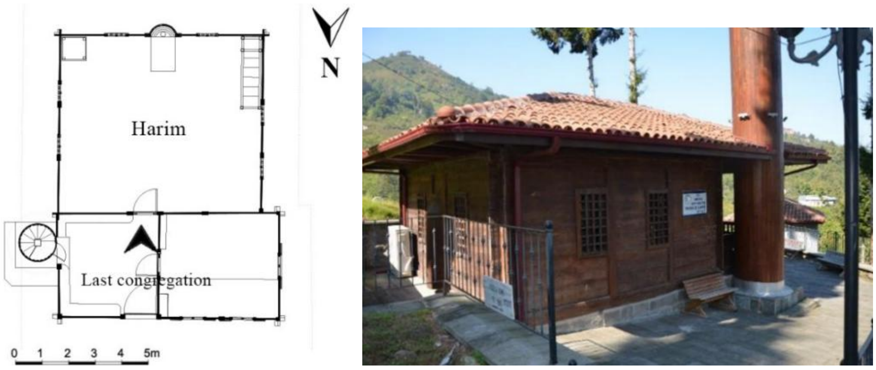

Fig. 7. Masele Mosque (Drawing: TVBM; Sarı, 2021)

2.5. Sürmene, Çamburnu Neighborhood, Kuşluca Mosque (1893)

Kuşluca Mosque is located in Çamburnu Neighborhood, east of the coastal part of the Manahos Stream Valley. According to the documents in the archive of the Trabzon General Directorate of Foundations, the mosque was built in 1893 (Önal and Köşklü, 2020).

The building has two floors, harim and mahfil floor. The last congregation is located on the north façade of the building and on the mihrab axis. The top of the last congregation is designed as an open sofa carried by six wooden pillars (Kazaz, 2016). A double-winged wooden door from the façade of the last congregation provides the entrance to the mosque. The semi-U-shaped mahfil floor is carried by four main pillars with a 20x20 cm section. A wooden staircase L placed in the northwest direction of the harim is used to reach this floor. The mosque was built with wooden masonry techniques throughout the harim, and the mahfil floor, and the kurtboğaz technique was used at the corners. Intermediate pillar elements were placed at an average of 2 m intervals along the wall.

Fig. 8. Kuşluca Mosque (Drawing: TVBM; Url 4)

2.6. Çaykara, Taşkıran Neighborhood Mosque (1897/1898)

The mosque is located on a sloping land in the east-west direction. According to written sources, the building was built on Hijri 1315, Gregorian 1897/1898 (DOKAP, 2019). It is the last example of the traditional mosques identified (Karpuz, 1990).

It was built with two floors, the harim and the mahfil floor. While there was no last congregation place in the original building, this section was added later. The entrance to the mosque, which has a rectangular plan along the mihrab axis, is provided from the west façade (Kazaz, 2016). A staircase from inside the harim accesses the mahfil floor. The entire perimeter of the upper floor is designed as a mezzanine. While the harim floor of the building is approximately 80 cm thick stone wall, the mahfil floor is made of wooden masonry. Kurtboğaz technique was used at the corners.

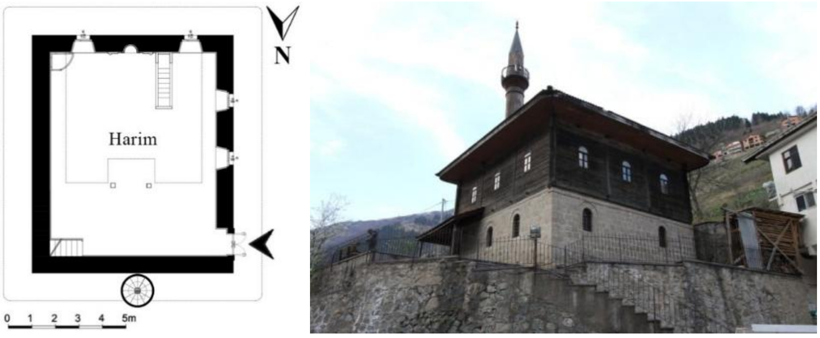

Fig. 9. Taşkıran Mosque (Drawing: TVBM; Url 5)

It can be said that the main elements that determine the typologies of the six mosques built with wooden masonry technique in rural Trabzon and evaluated within the scope of the study are the form of the main worship space, the presence, and location of the last congregation place, the presence and shaping of the mahfil section, construction technique and material use.

In this context, for these mosques, the main worship space shaped in the direction of the north-south mihrab axis, Uzungöl Filak Mosque, Güney (Kondu) Neighborhood Mosque, Kuşluca Mosque and Taşkıran Mosque have rectangular forms. In the Merkez Eski and Masele Mosque in the center, the harim has a form close to the square. The common point in the mosques with a square main worship space is the addition of another room to the north of the harim

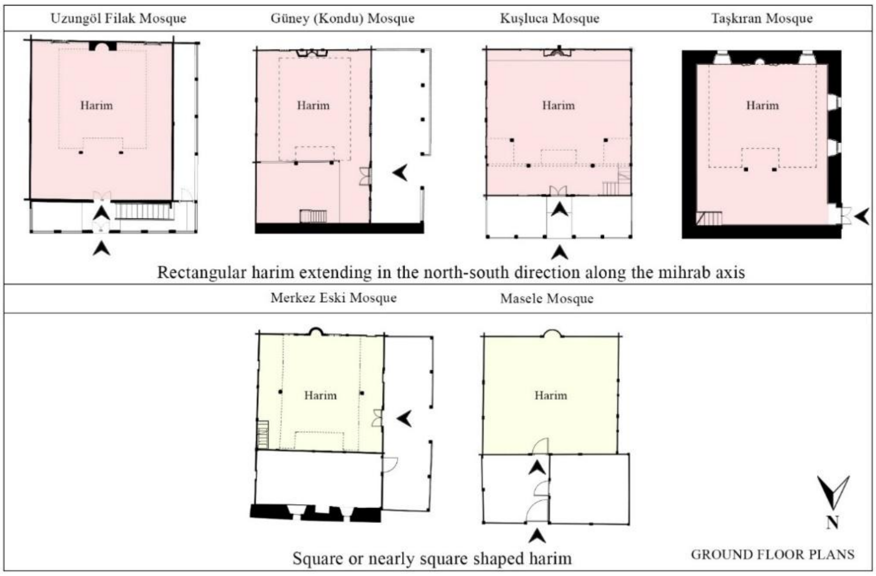

Fig. 10. Harim dimensions of rural mosques in Trabzon region (Drawing: Reproduced from TVBM archive)

The last congregation space is not present in some of the mosques in the region, and its position changes according to the mihrab axis. In Taşkıran Mosque, the last congregation area was added later, and this section was not present in the original building. In Uzungöl Filak Mosque, Kuşluca Mosque, and Masele Mosque, the last congregation place is on the mihrab axis and is located in the north direction. In the Güney (Kondu) Neighborhood Mosque and the Merkez Eski Mosque, this section is located on the west wing of the harim. Depending on the land conditions and the buildings' topography, the last congregation's location are varied. In mosques, if there is another room other than the harim, entrances to this space are provided from the last congregation place.

In some of the mosques of the region, the last congregation place was designed as an outer sofa with a function similar to the 'hayat' of rural houses. This area, with wooden poles and a covered roof, has turned into a place where the congregation socializes before and after prayers, waits for the time of prayer, has conversations and classes are held when the weather conditions are appropriate (Karpuz, 1989; Karpuz, 1990). Uzungöl Filak Mosque, Kuşluca Mosque, Güney (Kondu) Neighborhood Mosque, and the Merkez Eski Mosque are examples of this kind of use of the last congregation place.

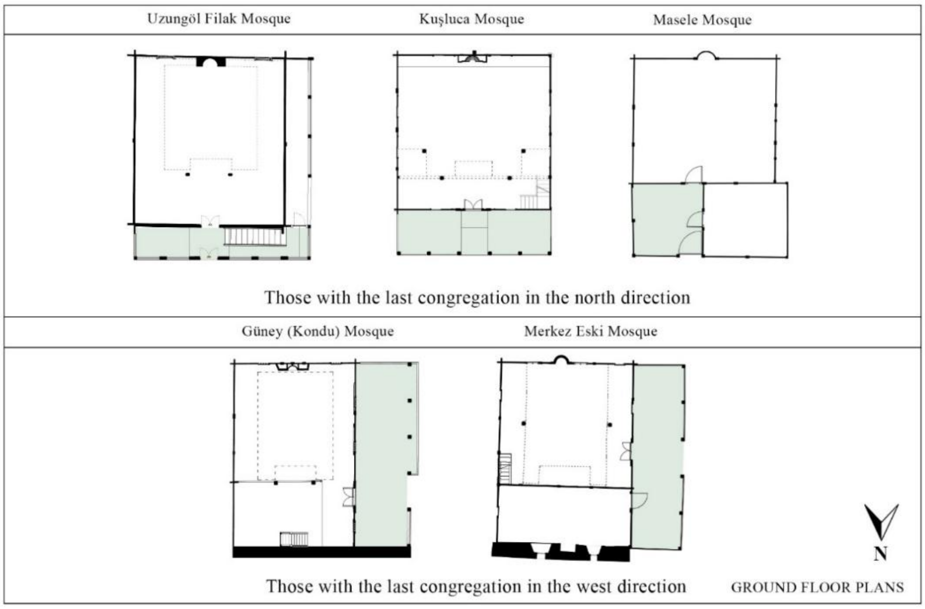

Fig. 11. The location of the last congregation place of rural mosques in the Trabzon region (Drawing: Reproduced from TVBM archive)

The system of use of the mahfil in mosques, a mahfil layout with a U-plan and surrounding the harim from three sides, is not a normal situation (Karpuz, 1989). This practice is seen in the Güney (Kondu) Neighbourhood Mosque and Merkez Eski Mosque, which are mosques in the region. In Kuşluca Mosque, the extending arms of the mahfil floor do not continue along the harim walls and are left halfway. The situation is quite different in Uzungöl Filak Mosque and Taşkıran Mosque. In these two mosques, the mahfil floor continues on the mihrab wall and surrounds the harim from four sides. This area above the mihrab is not wide enough for prayer. This situation has been stated as the allocation of the difference between the floors due to the different achievements of the ground and upper floors (Kazaz and Tuluk, 2021).

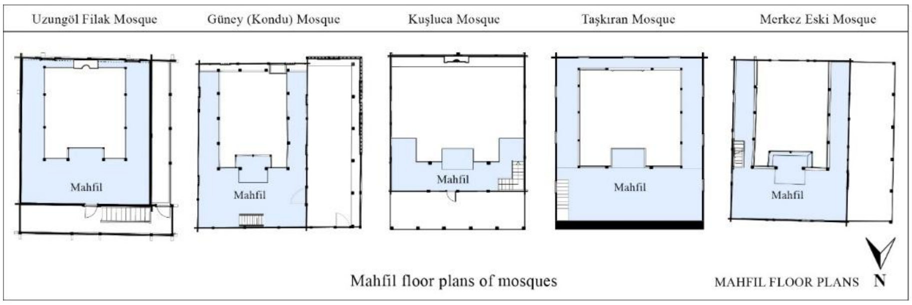

Fig. 12. Mahfil formations of rural mosques in Trabzon region (Drawing: Reproduced from TVBM archive)

The materials and construction techniques used in mosques should be evaluated together. Wood was used as the main material of the structure of the buildings. Mosques that were formed by joining 4-5 cm thick and rectangular wooden boards at the corners with the kurtboğaz technique (Özgüner, 1970) and have completely wooden masonry system walls are Masele Mosque and Kuşluca Mosque. Stone was used only in the main wall of the single-storey Masele Mosque. Although the main building structure is wooden masonry, it is possible to see different construction systems in the other four mosques. Göz dolma technique was preferred on the western wall of the basement of Uzungöl Filak Mosque, and the muskalı dolma technique was preferred on the mahfil floor of Güney (Kondu) Neighborhood Mosque. Stone masonry system was used in the basement floors of these two mosques. The harim floors of Taşkıran and Merkez Eski Mosques were built with a stone masonry system, and the mahfil floors were built with a wooden masonry system. The fact that many techniques are seen in a single mosque can be explained by factors such as the slope of the land where the building is located, its positioning, the function of the interior space, and material possibilities.

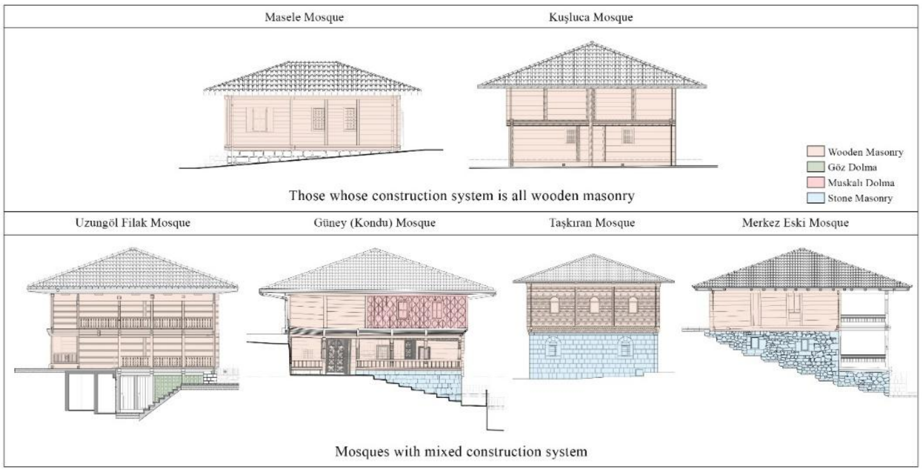

Fig. 13. Use of wood and stone materials and different construction techniques in rural mosques in the Trabzon region (Drawing: Reproduced from TVBM archive)

3. Comparison of Wooden Masonry Mosques in Georgia Adjara Region and Trabzon

When the administrative regions of Georgian geography are examined, the Adjara Region is important in terms of its proximity and border neighbor with Turkey in terms of geography, history, and socio-culture. Adjara Region came under Ottoman rule in the late 15th century. Batumi, the region's capital under Ottoman rule, was a sanjak attached to the province of Trabzon. 1921, the Autonomous Republic of Adjara was established as an autonomous republic. Apart from the capital, the large settlements called districts are Keda, Şuahevi, Kobuleti, Hulo, and Helvaçavuri (Seçkin, 2018). Islam increased in this region during the Ottoman rule. Therefore, there are examples of traditional mosques built with appropriate plans and architectural schemes under the influence of Islam that have survived to the present day (Kaya, 2022).

Fig. 14. Map of Georgia and Adjara Region (Url 6)

As a result of the literature research, it has been determined that there are similarities and differences between the original wooden masonry technique mosques built in the rural area of Trabzon province in the Eastern Black Sea Region of our country and in Georgia during and after the Ottoman Period. Within the scope of the study, a few examples of wooden masonry technique mosques in the Adjara Region of Georgia were selected to be compared with the rural area of Trabzon. The mosques will be examined comparatively under subheadings such as plan scheme, harim and mahfil arrangement, presence and characteristics of the last congregation place, material, and technique.

3.1. Plan Scheme

In the plans of rural mosques in the Adjara Region, the land conditions, the materials used, and the knowledge of the master builders are decisive. As in the mosques in Trabzon, the mosques in the region basically consist of a harim, mahfil, and last congregation place. Mosques have a rectangular plan scheme and are close to square in width or length according to the mihrab wall.

The harim is designed in mosques as a rectangular plan close to the square along the north-south mihrab axis. There are wooden poles and a wooden staircase in the harim that carry the mahfil on the upper floor. The last congregation place can be positioned in three directions except for the south side of the harim.

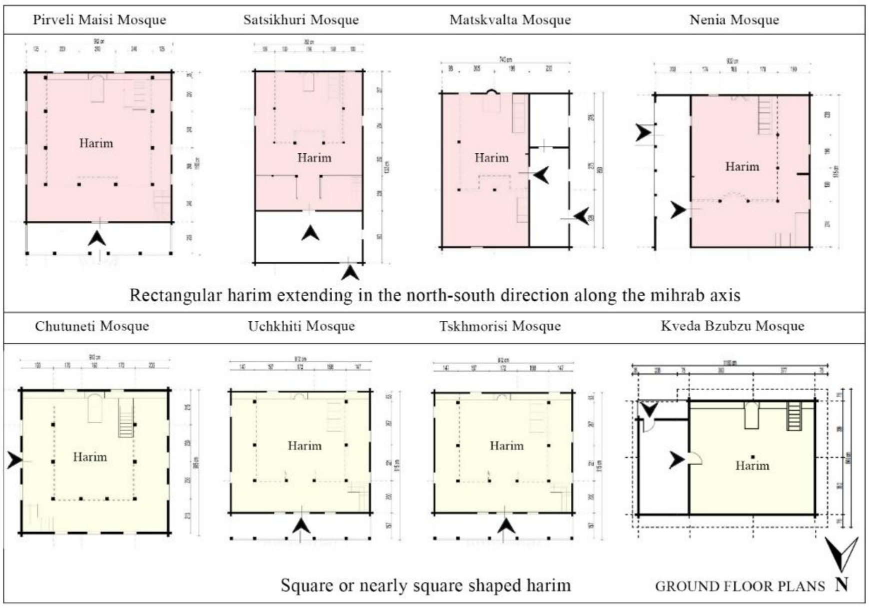

Fig. 15. Dimensions of the harim of rural mosques in Adjara Region (Drawing: Kaya, 2022)

In mosques, the north-south oriented and rectangular planned mosques on the qibla wall axis can be given as Pirveli Maisi Mosque (1720), Satsikhuri Mosque (1831-32), Matskvalta Mosque (1842), Nenia Mosque (1887), Medzibna Mosque (1910), Beghleti Mosque (1909). In these mosques, the harim has a rectangular plan regardless of the location of the last congregation place and entrance door. Examples of mosques with prayer spaces shaped almost like a square are Chutuneti Mosque (1826), Uchkhiti Mosque (1903), Tskhmorisi Mosque (1891), Kveda Bzubzu Mosque (20th century), Akho Mosque (1818), Agara Mosque (1809-10) (Kaya, 2022).

3.2. Last Congregation Place

When we look at the last congregation place of the wooden masonry technique mosques in the Adjara Region, it is possible to come across examples that are open or semi-open spaces supported by wooden poles that remain in the interior of the mosque, that are later closed or completely closed, or that do not have last congregation place. In some examples, the ample space left inside the harim and at the entrance is called the last congregation place. The location of this place varies due to factors such as the entrance door of the mosque, different rooms added to the mosque, topography, and slope of the land. In cases where the last congregation place is designed as a closed space, the wooden stairs leading to the mahfil floor are placed in this space.

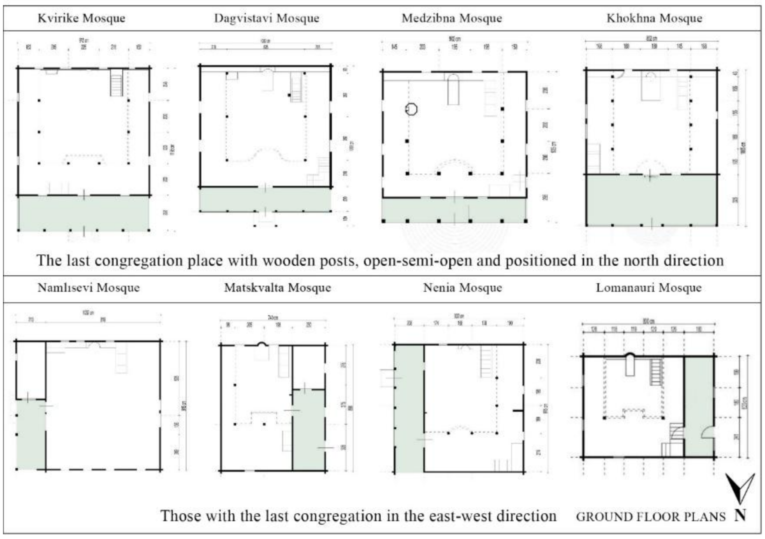

Fig. 16. Last congregation places of some rural mosques in Adjara Region (Drawing: Kaya, 2022)

Similar examples to Uzungöl Filak Mosque and Kuşluca Mosque, where the last congregation place is on the north side and has the feature of an entrance with wooden pillars, are Kvirike Mosque (1859), Dagvistavi Mosque

(1914), Pirveli Maisi Mosque (1720), Uchkhiti Mosque (1903), Medzibna Mosque (1910), Zundaga Mosque (1903), Khokhna Mosque (1900). Examples of mosques where the last congregation place is on the east or west axis, as in Güney (Kondu) Neighborhood Mosque and Merkez Eski Mosque, are Namlısevi Mosque (19th century), Kveda Bzubzu Mosque (20th century) Matskvalta Mosque (1842-43), Nenia Mosque (1887), Lomanauri Mosque (20th century). In Zeda Agara Mosque (19th century) and Beghleti Mosque (1909), the last congregation place was built as a closed entrance space, and there is a direct passage between it and the harim without an entrance door. In Ghorjomi Mosque (1902), the last congregation place has a different layout and makes a T-shaped protrusion to the north. In addition to these, there are examples in the mosques of the Adjara Region where the last congregation place is not defined as a separate space and is inside the harim. Tago Mosque (1900-15), Darchidzeebi Mosque (1840), Mahalakidzeebi Mosque (1760), and Kviakhidzeebi Mosque (1889) are among these types of mosques. In addition, there is no narthex in Chutuneti Mosque (1826) as in Taşkıran Mosque (Seçkin, 2018; Kaya, 2022).

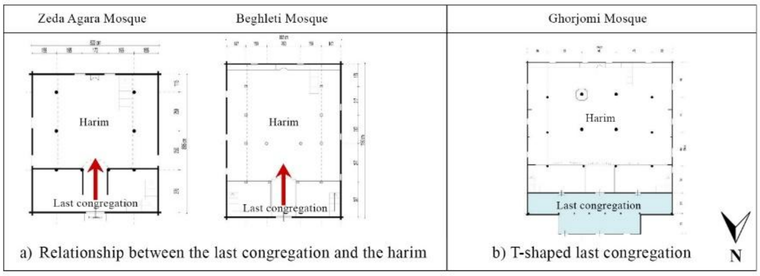

Fig. 17. Zeda Agara Mosque and Beghleti Mosque last congregation-harim relation b) Ghorjomi Mosque T-shaped last congregation (Drawing: Kaya, 2022)

3.3. Mahfil Arrangement

Mahfils were developed in small-scale rural mosques due to the insufficiency of the congregation and the idea of creating a space suitable for women, which is seen in mosques in the Adjara Region (Kaya, 2022). The mahfil arrangements of these mosques mostly have a U-shaped form surrounding the harim. The mahfil is carried by wooden poles rising in the harim on the upper floor. The mahfils, whose north side is wider, are left narrower on the east-west sides and end at the qibla wall. There are protruding kiosks on the north wing, as in the rural mosques of Trabzon. The mahfil example extending only along the north façade is found in the Zeda Bzubzu Mosque (1820-60). There is no mahfil arrangement in the Kveda Bzubzu Mosque (20th century).

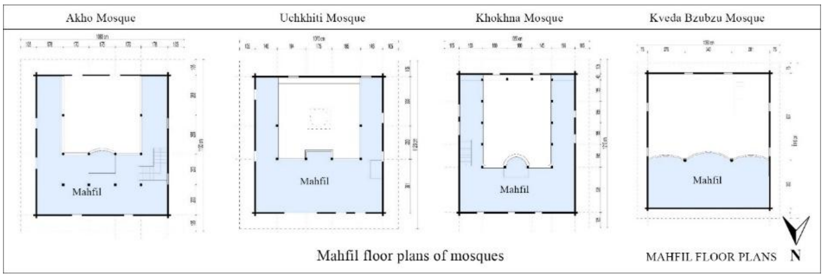

Fig. 18. Mahfil arrangements of some rural mosques in Adjara Region (Drawing: Kaya, 2022)

3.4. Material and Technique

The main construction material of the exterior and interior architecture of the regional mosques, except for the basement, is wood. As in the Eastern Black Sea region, chestnut, walnut, pine, oak, spruce, beech, and elm (tela) trees, which are resistant to heat, humidity, and external conditions for a long time, were used in the structures (Aytekin and Kaya, 2024). Stone material is seen in the basements of the regional mosques and in the basements of sloping lands. Like the mosques examined in the Trabzon countryside, the wooden masonry system was applied intensively in the mosques of Adjara. Some of the mosques that can be included in this group are given in Fig. 19.

In mosques, the wooden stacking system continues for two floors, including the harim and mahfil floors. Examples of mosques that are rarely three-storey and are entirely constructed of wooden masonry include the Darchidzeebi Mosque and the Medzibna Mosque. The common point in these mosques is the use of stone instead of wood on the façades where the basement is buried due to the slope of the land. As in Trabzon mosques, wooden walls are stacked on top of each other between the main beams and joined at the corners with the kurtboğaz technique. In cases where the length of the wooden boards is not sufficient, intermediate posts are placed, and a complete wall appearance is achieved by using the two or three-channel çalma boğaz technique. Unlike the rural mosques of Trabzon, some façades of Adjara mosques are covered with aluminum material to protect the structure from external factors. At the same time, examples have been seen where all of the wooden surfaces on the façade are painted. While there are thicker wall sections in Trabzon mosques where the göz or muskalı dolma technique is used in addition to wooden masonry, it is impossible to come across these techniques in the Adjara Region. However, from the oldest façade photograph of the Tago Mosque, it is thought that the wall where the entrance door is located has features similar to the göz dolma technique.

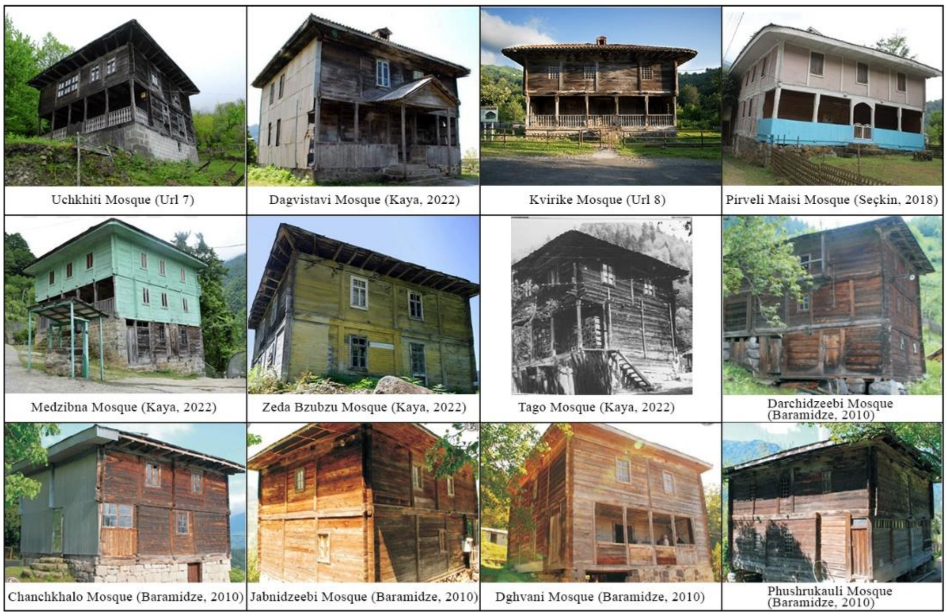

Fig. 19. Adjara Region mosques built with wooden masonry technique

The çantı mosques are seen in two different types in the Black Sea Region in terms of the plan, spatial features, façade, mahfil arrangement, and construction system. The Seljuk and Early Ottoman Period I. group çantı mosques have a longitudinal rectangular plan and are single-storey, and the mahfil is to the north of the harim. The 18th-20th century Late Ottoman Period II. group mosques have a rectangular or nearly square plan, are two-storey, and are built in the form of a mahfil floor surrounding the U-shaped harim from three sides (Kaya, 2023; Aytekin and Kaya, 2024). Wooden çantı mosques continue to exist in both Trabzon and Georgia regions with similar typologies to their traditional original forms. The vast majority of these mosques have the characteristics of group II.

4. Conclusion

Within the scope of the research, other typological analyses can undoubtedly be made regarding the nature of the rural mosques of Trabzon and Adjara that are not included in the text. For example, architectural elements such as ornamental features, door and window details, façade arrangements, and permanent components of the interior such as the pulpit and mihrab can be evaluated. The study is limited to the distinctive typological analyses between the basic components of the mosques in question, such as plan arrangement, last congregation place, use of the mahfil, materials, and construction techniques.

This study examined specific examples of wooden masonry (çantı) mosques, which are an important part of the rural architectural heritage of Trabzon and Adjara Region, which have a cultural past and geographical proximity throughout history. It was determined that these sample mosques have very similar plans, architectural features, and construction techniques. It is possible to explain this relationship between the regions with the increasing cultural exchange between the two geographies, especially during the Ottoman Period, the interaction of the construction masters, and the understanding of art and style similarities.

Due to the slopes of the land settlements, both regions' mosques were built on a high basement or basement floor. This situation increased the possibilities of using stone and wood together. It was also a solution to prevent the wood from rotting because of rainwater and humidity.

In Trabzon and Acara mosques, the last congregation area has gone beyond being a functional place for the congregation to pray, as in monumental mosque architecture. In most of the mosques in both regions, this area has become a transition and socialization area for the congregation and has been designed as a dış sofa. In addition, local masters have not been insensitive to the environmental elements in which the mosques in the region are located and have positioned the last congregation area not only in the north but also in different directions.

In both regions, all mosques are wooden masonry. Masonry walls relate to kurtboğaz at the corners and the middle of the walls with the çalma boğaz technique. It is seen that the masonry technique used in the mosques of Adjara as a result of the stylistic unity with the Black Sea Region was continued from the Seljuks to the Ottoman Period and later. However, in the rural mosques of Trabzon, the use of the muskalı and göz dolma techniques and the wooden masonry system is a characteristic specific to the region.

Mahfil floors generally surround the harim in a U-shaped manner on three sides in the Trabzon and Adjara Region mosques. According to the style of the master builders, there are examples of mosques in Trabzon with mahfils on the mihrab in addition to the three sides, and in the Adjara Region, there are examples of mahfils only on the north side. Different typological solutions can be encountered in the plan plane for mahfil floors in this context.

As a result, the wooden masonry mosques of Trabzon and Adjara Region, which are part of the regional building tradition, are rural architectural heritages that should be protected and transferred to future generations without deterioration. Today, due to the limited number of these mosques in rural areas, their deterioration due to lack of maintenance and natural conditions increases the risk of their extinction day by day. In mosques that have undergone repairs due to use, unconscious interventions have been made to the original elements. Cultural cooperation should be ensured between the two neighboring countries to repair and restore mosques. Thus, the architectural tradition of the wooden masonry mosques of the Trabzon rural area with their general layout plan, harim and mahfil floor arrangements, building materials, and construction solutions will be able to continue its continuity in the Adjara Region in distant geographies.

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The effect of Russian Era buildings on today's Kars City identity in terms of socio-cultural sustainability

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Abstract. Cultural heritage reflects the society's social, economic, and cultural values, and serves as a bridge between the past and the future. The socio-cultural sustainability of cities is possible with the common culture, history, and nature consciousness of the people living in the city. It is seen that today's urban sustainability studies are generally focused on environmental and socio-economic issues, while the socio-cultural sustainability aspect is quite neglected. In this study, the significance of the Russian period buildings in the city centre of Kars and their contribution to the city's identity were examined in terms of sociocultural aspects and architectural value. Russian buildings, which have undergone physical and functional changes for over a hundred years, were analysed thoroughly with their cultural, historical, and architectural features. The subject of the research is to examine the effects of physical changes on urban identity in terms of socio-cultural sustainability. In this study, historical photographs and engravings, projects, maps, and archive documents, as well as related literature, were utilised. The current conditions of the buildings were documented based on photographs, surveys, and restoration drawings. Questionnaires and in-depth interview techniques were used to determine the urban identity and socio-cultural sustainability relationship. As a result, historical Russian buildings are seen as a value by the local community and should be protected by giving them appropriate new uses and conserving the physical characteristics of the buildings. This approach would help enhance the urban identity and contribute positively to the socio-cultural sustainability.

Keywords: Socio-cultural sustainability; Urban identity; Urban memory; Urban conservation

1. Sustainable Development and Sociocultural Sustainability

Ideas such as using today's needs in a way that does not harm the resources that future generations will need, and harmonizing between human and natural order are the basis of sustainable development. Sustainability aims to reduce our future carbon footprint through sustainable development principles and sustainability criteria, increase economic efficiency, protect and repair ecological systems, and increase the welfare of everyone on a social and environmental scale (Sırkıntı, 2012).

With the Industrial Revolution, mechanization in production processes accelerated in the 18th and 19th centuries; this development led to the dissolution of rural life, cities becoming centers of attraction and large-scale migration movements. With this transformation in production, environmental problems have also increased, natural resources have been overexploited and unplanned urbanization has brought new social and ecological problems

The concept of sustainable development, which has the characteristics of a solution after the negative conditions experienced, started to show itself in the 1990s with sensitive and respectful policies in the economy and the studies carried out in the protection of the natural environment, and it aimed to serve egalitarian, egalitarian, goals on a social, economic and environmental scale with human-oriented studies, to make joint decisions with the participation of everyone in all studies that will benefit and to allow equal opportunities (Şenel, 2010). There are policies that countries need to carry out to achieve the efficiency they aim for in the sustainable development process. Among these, global responsibilities, participatory approaches, common approach strategies, and sustainable urbanization policies constitute some of the basic principles.

The concept of sustainable development was officially defined in the document called Our Common Future, known as the Brundtland Report, published by the United Nations World Commission on Environment and Development in 1987 (Bulut & Taş, 2017). In the report, sustainable development is defined as a development model that aims to meet the needs of the present without jeopardizing the opportunities of future generations.

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In this context, sustainability is an environmental approach and a multidimensional way of thinking that includes economic and social responsibilities. This understanding aims to create change in consumption habits, solidarity based on equality, and a future-oriented development approach. Sustainability is evaluated on three main axes: environmental, social, and economic, and these dimensions are considered as a whole (Şenel, 2010).

The framework of environmental sustainability aims to use the raw material resources that meet the basic needs for vital activity, which exist spontaneously in nature, in line with the necessary needs, and to avoid unnecessary use and waste that cause great destruction on an environmental scale. In economic sustainability, as in environmental sustainability, the aim is to monitor the process by taking into account the ecological balance in the supply and use of basic raw materials. With every development, an undisturbed living space and usable raw material resources should be considered together with the economic accumulation to be left to future generations, and strategies should be followed in this context. Social sustainability is the development of social structure and environment, beliefs and lifestyle, education, and personal attitudes following social balances. It aims to ensure fairness in the level of welfare and to have equal social status. The basis of social sustainability is the provision of constitutional rights and basic vital activities such as the opportunity to work in appropriate criteria, suitable living space, health, access and transportation, social environment, right to education, regardless of the status in the society (Özçuhadar, 2007).

Societies that want to continue to exist in future generations care about the evaluation of cultural values, structures, and environments within the social and cultural framework and aim to leave these values as a legacy for the future. Environmental sustainability on an environmental and ecological scale to create a livable environment and social space, economic sustainability in the development of systems that allow the long-term use of raw materials and existing resources, socio-cultural sustainability that provides opportunities in standard quality of life under the rules of social order of societies and ensures that cultural heritage is maintained without losing its material and spiritual values.

Socio-cultural sustainability includes the preservation of the physical integrity of buildings with historical and traditional textures as well as their cultural meanings. In this process, it is of great importance not only to preserve the buildings but also to document their original qualities such as architectural plans, construction techniques, and material properties, and to shape conservation policies in line with these documents (Yazıcı, 2020).

Sociocultural sustainability, which is formed by social and cultural values, which are among the important phenomena that make up the urban structure and culture, is evaluated with different qualities and criteria. In this context, these criteria are considered as social, cultural, and physical dimensions. The physical dimension covers issues such as physical spaces, urban environments, energy efficiency, natural environment, and the proper use of the natural environment. The social dimension covers issues such as ownership, belonging, justice, social values, and equality. The cultural dimension covers issues such as tradition, custom, cultural values, and historical environment (Çahantimur and Turgut Yıldız, 2008). Although these dimensions have different meanings, they have many points that serve a common purpose. By protecting and sustaining the physical environment, the values attributed to the social dimension are also protected, and in the cultural dimension, the historical environments and cultural values in question have survived to the present day (Barke, 2018).

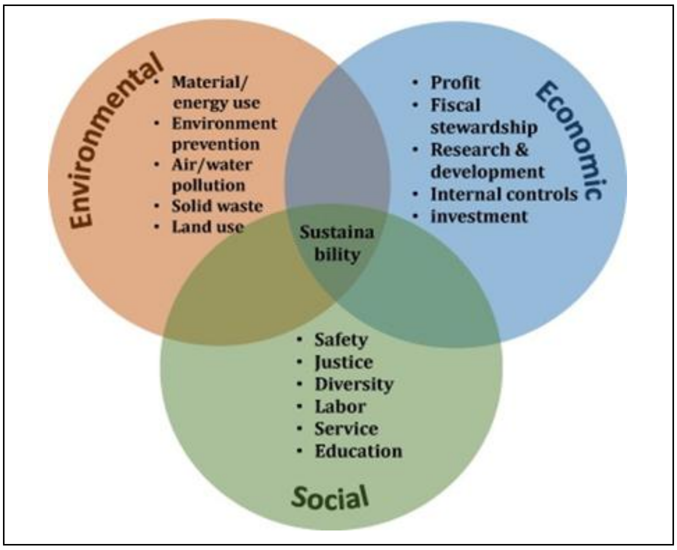

Fig. 1. Dimensions of sustainability (Şenel, 2010).

2. City Identity

The most important features that allow cities to have an identity and show different characteristics from each other are the unique features of the city. These features can be expressed as the location, population density, demographic structure, traditions, customs, architectural style, and socio-cultural conditions of the city. The thoughts that come to mind about a city or, in other words, the way the city is described in the mind and the thoughts determined about the city in the mind when visiting the city express the city's identity (Kaya Özdemir, 2016).

The role of architectural features in the identities of cities is quite high. Architectural features of the periods, materials used, plan shapes, facades, windows, and ornamental elements all provide information about the city's identity (Kaya Özdemir, 2016). However, with the industrial revolution and the invention of the steam engine, developments in cities, job opportunities, quality living options, and the attractive features of urban life resulted in rapid and intensive migration of people from rural areas to cities and increased the population in cities. To meet the housing needs of the population density in the cities, fast-production housing constructions have become widespread with the help of developing technologies, and uniform and similar buildings have emerged as a result. In addition to the positive contributions provided by technology, such an application at the urban scale has made cities fit into a certain scale and has confronted them with the possibility of becoming uniform over time. This situation is a phenomenon that damages the identities of cities and de-identifies them.

Today, de-identification and the lack of identity in cities have become one of the most important problems. This situation has negative consequences for the city in social, economic, cultural, and environmental dimensions and causes users to move away from a sense of belonging.

It is an important fact that the city is far from being alive and static, as opposed to being an abstract and inanimate formation. It is important to adopt the traces of the past, historical roots and cultural values, to protect the identity of the city, to protect its identity (Bingül, 2004).

2.1. Sustainability of Architectural Identity

It should be said that the structures that best reflect the architectural style in cities are historical places, monuments, squares, parks, and gardens. These structures, which constitute the unique architectural style of each city, should be transferred to future generations, and the urban identity should be sustainable. Therefore, this sustainability is possible through conservation, restoration, and transformation projects. Revitalizing historical buildings that have lost their original function with new uses suitable for the needs of the age contributes to the preservation of architectural character and increases social awareness. Such interventions reinforce the public's attachment to cultural heritage and keep alive the historical and cultural meaning of the building beyond its physical existence. These buildings, which bear traces of different civilizations, thus build a bridge between the past and the present, becoming the common values not only of the present but also of the future. In this way, cultural heritage can preserve its existence despite the corrosive effects of time and can be kept alive for generations.

3. Russian Period Buildings in Kars

Located in the extreme eastern part of Turkey, this city has a surface area of approximately 9,939 km² and is situated considerably above sea level with an average altitude of 1,756 meters. Most of its territory consists of the plains of the Kars-Erzurum plateau, which runs in a northeast to southwest direction. An analysis of its urban structure and architectural character reveals that the Russian rule, which lasted from the last quarter of the 19th century until the early 20th century, left deep traces on the city. Buildings and planning approaches from this period are still evident in the urban fabric today (Ekici & Şahin Gürcan, 2022).

3.1. Urban Development in Kars during the Russian Period 1878-1918

Kars, which has been the scene of many military conflicts throughout history due to its strategic location, has been one of the focal points of the Ottoman-Russian struggles. Russia considered Kars as a key region for the passage to Anatolia and fought three wars with the Ottoman Empire before the Treaty of Berlin in 1878. These conflicts caused great destruction in the city. The Russians, who annexed the region to their territory with the Treaty of Berlin, created a new administrative unit centered on Kars (Serbest & Savaş, 2012). The administrative structure in question consisted of four sub-regions, namely Kars, Ardahan, Kağızman and Oltu, and led not only to an administrative change but also to radical transformations in the city on social, economic, military and spatial levels. During the period of Russian rule, the influence of Russian culture spread rapidly in the city, and experts and entrepreneurs brought from Europe played an active role in the reshaping of the city through various projects for the modernization of Kars (Fig. 2) (Serbest & Savaş, 2012). The fact that the region was located on the border between the Ottoman and Russian Empires brought Kars to the forefront in terms of military logistics. Accordingly, a railroad line starting from Russia and extending to Sarıkamış was built in 1899 to facilitate future military shipments. This line, which was considered a continuation of the Batum-Tbilisi customs line, has historical significance as it was the first railway line built in Anatolian lands outside of Ottoman control (Yavuz, 2012).

During the 40 years of Russian sovereignty, which had a great impact on the formation of today's urban fabric in Kars, an urban phenomenon was created in a grid system that cut each other perpendicularly on the plain called

Tahtdüzü to the south of the castle and Kars Stream without touching the civil architecture built during the Ottoman period on the skirts of the castle (Ortaylı, 1978). The city started to be built around the grid plan system formed by the intersection of 8 streets, 4 in the north-south direction and 4 in the east-west direction (Fig. 3) (Kesici, 2022). In this urban planning, some corner parcels were used as public spaces, squares, and parks.

In the buildings constructed during the Russian period, entrances were mostly provided through the main façade of the building, while public and administrative buildings were generally located at the junction of streets and avenues. This layout was supported by wide pedestrian paths, adding both order and visual richness to the city skyline. Balconies, which are frequently encountered in the building plans of that period, stand out as an important aesthetic element, especially in official buildings. While these balconies added splendor to the buildings, a simpler ornamentation approach was adopted in the residences offered for public use. Compared to official buildings, more restrained decorations were preferred in residential areas, and it was aimed to provide access to residences through side entrances to courtyards as well as entrances to the street (Alınak, 2022).

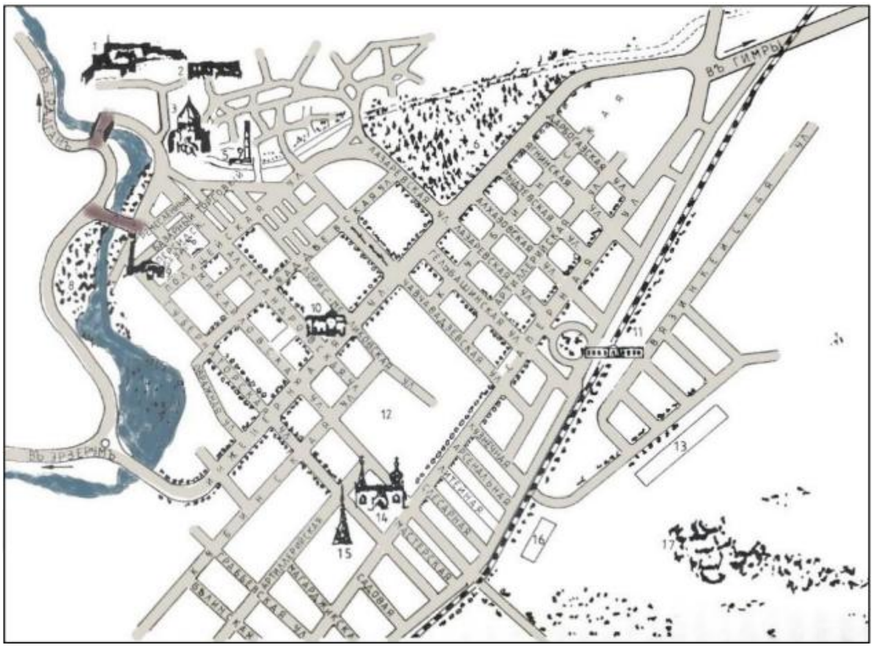

Fig. 2. 1910 Russian Period Kars City Plan (Alınak, 2022).

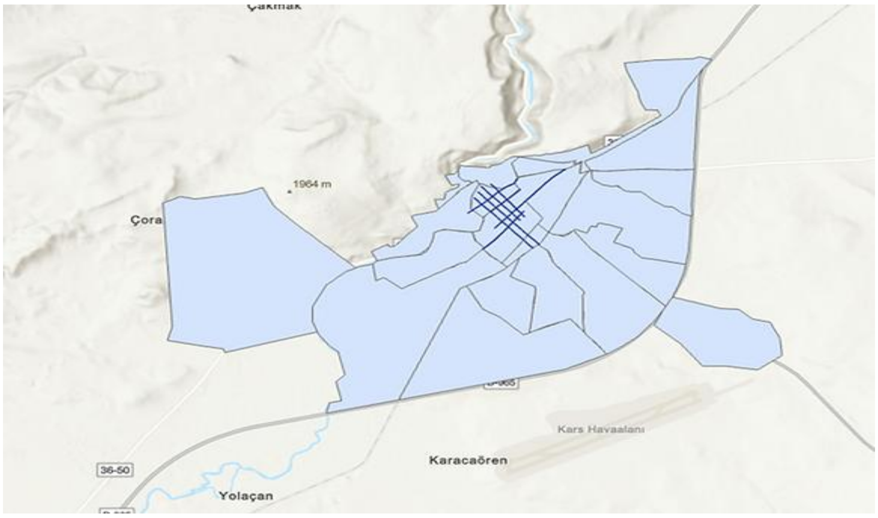

Fig. 3. Grid Plan Developed by the Russians in Kars (Kesici, 2022).

3.1.1. Russian Period Buildings in Kars City Center

The Russian period buildings in the city center of Kars have continued their existence by changing their uses over time and are still in use today. During this process, architectural features and strategic locations of the buildings contributed to the urban identity. Fig.s 4 and 5 show that many structures in the city center have different functions and have been transformed over time according to local needs. Within the scope of the paper, the physical, social, and cultural characteristics of the Kars Chamber of Commerce and Industry Building, the Kars Financial Affairs Directorate Building, and the Kars Municipality Building located on Karadağ Street are examined in terms of sociocultural sustainability and their effects on the identity of the city.

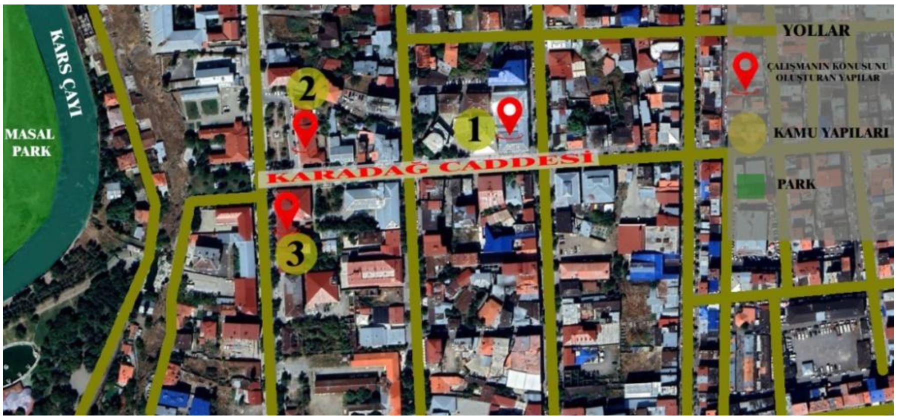

Fig. 4. Location of Buildings, Roads and Parking Areas are indicated on the map taken from Google Earth

Fig. 5. Location of the buildings to be examined in the study in the urban fabric

Fig. 6. Kars Chamber of Commerce and Industry Building

The building was built in the 19th century and its current use is as a public building and its first use was a public building. The building is planned in L-form and consists of two floors: the basement and the ground floor (Fig. 6). During the construction process, cut basalt stone and masonry rubble stone were preferred as the basic building materials (Fig. 7.A). Although no significant deterioration or intervention was observed on the facade of the building over time, significant changes were made in the interior space depending on the user needs. Interventions such as the removal of existing interior walls and the addition of new sections have drastically changed the original plan layout of the building (Fig. 7.B).

Due to urban development and changing needs, new buildings built around the existing ones are in a visual and functional competition rather than for integrity. This situation causes economic gain and profit-oriented approaches to come to the forefront; as a result, it has negative repercussions on urban identity at physical, cultural, and socio-economic levels. With the proliferation of similar buildings, an urban texture without identity is formed, far from the human scale. While this transformation causes the values that make the city unique to fade, it also makes it increasingly difficult to preserve cultural continuity and urban memory.

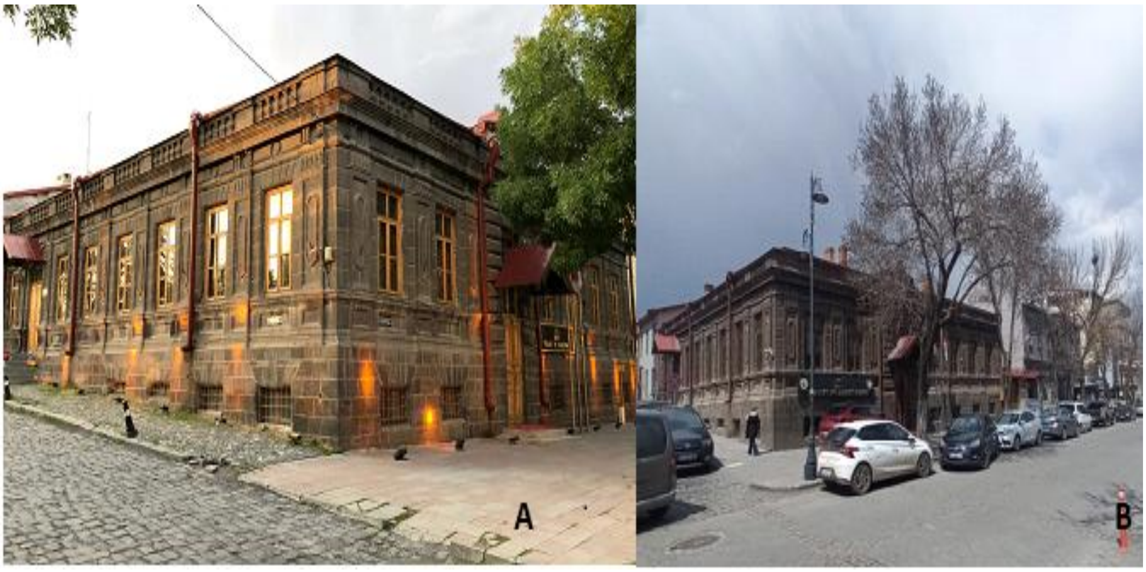

Fig.7. Kars Chamber of Commerce and Industry Building before (A) and after (B) adaptive re-use.

Fig. 8. Kars Treasurer's Office Building

Fig. 9. Kars Defterdarlık Building A. Original building, B. Current condition.

The building was built in the 19th century, and its current use is as a public building; and its first use was as a theater. The building has a total of three floors: basement, ground floor and first floor and is planned in a U-shape (Fig. 8). Different materials such as smooth cut andesite stone, black cut stone and rubble stone were used together in the construction of the building, which has entrances from two different points (Fig. 9.A). Among the architectural details, the cartouche-style ornaments concentrated especially around the windows and corners attract attention. This building, which stands out among the buildings from the Russian period with its magnificent architecture and large scale, has a symbolic value for both the people of the city and the visitors.

It is observed that the building is not in physical harmony with other buildings in its surroundings, and exhibits a fragmented and disconnected structure instead of forming a unity with the urban fabric (Fig. 9. A). Such incompatibilities lead to the emergence of irregular and unrelated architectural formations along urban axes, which negatively affect both the physical environment and the socio-economic, cultural, and demographic structures that make up the urban identity. Repetitive and unidentified construction examples that are far from spatial integrity pave the way for the formation of an environment that is foreign to the urbanites. This situation transforms the urban identity and the imaginary elements that constitute it, leading to a process of change that will weaken these values over time and threaten the sustainability of sociocultural heritage.

Fig.. 10. Kars Municipality Building

The structure was built in the late 19th century, and its current use is as a public building; and its first use was as a school. The structure, which is located on the corner parcel where Karadağ Street and Atatürk Street intersect, was built as a basement and ground floor during the period it was built, and later on, a first floor was added in the early 20th century. The plan of the structure has an L-shaped plan (Fig. 10). The facade of the structure, which has a significant value for locals and visitors to the city, bears very important traces from the period it was built with recessed columns, plant and geometric motifs, and balcony projections (Fig. 11.A).

After the declaration of the Republic, a new addition was added to the building that served as the municipality building, and the entrance to the building was provided through a glass door between the old and new buildings. The entrance leads to a courtyard with a glass ceiling on a lattice system. And from this courtyard, there are transitions to the building built during the Russian period and the addition added later (Fig. 11.B). There is another main entrance on the Karadağ Street side of the building, built during the Russian period. Although the section added later to the building complies with traditional systems, it disrupts the integrity of the existing structure. Due to investment-oriented urban policies, the transformation process of the structures makes it difficult to sustain socio-cultural values and preserve urban identities.

Three representative structures from the Russian period on Karadağ Street were examined (Fig. 12). There are structures built using new construction techniques along the street. The structures remaining from the Russian period domination process add a unique identity to the street and the city. However, the structures have undergone transformation and change with interventions and renovations in the process. Although these are not significant on the facade of the structure, they are dense in terms of plan and usage functions. There are two more historical structures examined along the street and the exterior. There is a structure and street plan that does not comply with the current texture and historical structures in terms of density. It is understood from the interviews that the structures that have historical value and heritage for the future also have cultural value for the city's people. Today, there are historical structures that keep the social and cultural values that are about to be forgotten alive in many parts of the country. Each structure carries an identity value. The Russian structures in Kars province are at a low damage percentage at this point.

The physical, social, cultural, and urban identity characteristics of Karadağ Street and the buildings on it will be evaluated (Table 1).

Fig. 11. Kars Municipality Building A. Original building, B. Current condition

Fig. 12. Views from the Karadag Street

Table 1. Evaluation of socio-cultural sustainability and urban identity of the buildings located on Karadağ Street

Building Name/Type	Construction Date	Social Sustainability Contribution	Its Relationship with Urban Identity	Current Use/Status
Kars Treasurer's Office	19th century	Provides social equality by increasing access to public services.	It is a part of the tradition of the state's continuity and public administration	It is still serving as a public building.
Kars Municipality Building	20th century	It serves as an important center for the local government to meet the citizens.	It is the building block of identity as the political and administrative representation mechanism of the city.	It is active as a municipal service building.
Kars Chamber of Commerce and Industry Building	20th century	It contributes to sustainable development by supporting the development of local economic institutions.	It strengthens the economic identity by reflecting the history of trade and production.	It continues its function as a Chamber of Commerce

4. Conclusions

In recent years, the rapid cultural and spatial transformations in our country have had a great impact on streets, one of the most important components of urban areas, and the urban images formed by these streets. Rapid changes in the city lead to the rapid loss of street texture, street structure, and the identity that forms a whole with the environment. Considering the interaction of old and new structures, the relationship between streets, transportation networks, and people should be reconsidered, and a sustainable urban life should be created in this context. In particular, the streets and surrounding urban areas, which have lost their identity, should be reshaped by adapting to the changing cultural structure. In this process, rational and logical approaches should be adopted in the reconstruction of urban identities and images, rather than aesthetic or fashion-based solutions.

The development processes and functional characteristics of cities are often filled with similar buildings shaped by economic concerns, rather than ensuring integrity with the buildings built around them. This situation negatively affects the physical, socio-economic, cultural, and demographic structure of urban identity and creates an alienated environment. The basic values that constitute urban identity and urban images are undergoing processes of change and transformation, which create great difficulties in ensuring the continuity of socio-cultural values and preserving urban identities. However, social sustainability is a topic that has been addressed less than other aspects of sustainability; comprehensive analyses and in-depth studies in this field will reveal important practical results both today and in the future.

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Structural techniques of northern Iran: Traditional methods and sustainability

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Abstract.
This paper examines the traditional construction techniques of houses in the village of Asiabar in northern Iran, focusing on two types of walls: Zegali and Darvarjin. Each of these structures has been designed with unique features to adapt to the environmental and climatic conditions of the region. Zegali walls are typically built on Pakuneh foundations, utilizing carved wood and specific construction methods to ensure better stability and performance against environmental changes. In contrast, Darvarejin walls, which are older and now less common, are constructed on compacted earth or stone foundations, with horizontal logs and mud filling the gaps between them.
This study specifically analyzes the structural and functional differences between these two types of walls, examining factors such as the placement of wood and the types of foundations used. The construction of sloping roofs, supported by Bam Dar beams and covered with materials like Latte Sar or metal sheets, is also explored in the context of the village.
The aim of this paper is to provide a detailed analysis of these traditional construction techniques and their impact on the durability and stability of the structures. This research can contribute to the improvement of traditional design practices and the recognition of local architectural values in similar regions.

Keywords: Traditional construction, Zegali wall, Darvarejin wall, Pakuneh foundation, Local architecture.

1. Introduction

Providing affordable and resilient housing is one of the fundamental needs of any society. Achieving this goal relies heavily on the efficient use of materials and the application of engineering knowledge to optimize construction methods (Oliver, 2006). After the 1990 Gilan earthquake, it became evident that certain wooden houses, designed with appropriate frames and foundations, remained largely intact, suffering only minor and repairable cracks (Charkhtab Moghaddam & Roohanian, 2014). This highlighted the resilience of traditional construction methods in seismic regions. Wood, as a lightweight and environmentally friendly material, offers high resistance to both tensile and compressive forces and has been used for centuries in beams, roofs, and wall structures (Herzfeld, 2002). Its flexibility and energy absorption capacity make it a valuable material in earthquake-prone areas (Brzev, 2007). In Iranian vernacular architecture, wood and mud have been widely used due to their availability, low cost, and climate responsiveness (Memarian & Brown, 2006). Despite these advantages, traditional wooden techniques are now less commonly used, and their technical logic is at risk of being forgotten. Iranian vernacular architecture has historically adapted to local climates and available materials, producing solutions that meet both functional and environmental needs (Foruzanmehr & Vellinga, 2011). This study focuses on the traditional village of Asiabar in northern Iran, located in a humid, mountainous region. In the foothill regions of Gilan Province—characterized by a temperate climate, high humidity, and frequent rainfall—housing must address not only the basic need for shelter but also provide climatic comfort. The vernacular architecture of the village of Asiabar, like that of many rural settlements, has been profoundly shaped by environmental conditions. To prevent moisture infiltration from rain and snow, roofs are constructed with two or four slopes. Compared to the lowland areas, these mountainous regions experience lower humidity but colder temperatures, leading to more enclosed building envelopes and fewer semi-open spaces. Semi-open areas are typically limited to the main façade of the first floor and are often protected with wide doors and windows. Building orientation is carefully planned to benefit from desirable winds that help reduce humidity, while avoiding harsh winter winds, regional warm gusts,

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and driving rain, thus fully responding to the region's climatic requirements. The aim of this paper is to analyze the construction techniques of two traditional wall types—Zegali and Darvarjin—through a detailed investigation of their structural systems, from the foundation to the roof. By examining elements such as the type of foundation, placement of wooden beams, wall composition, and roofing methods, this study seeks to highlight the structural logic and environmental adaptability embedded in local construction practices.details — from the foundation to the roof — are examined to gain a better understanding of these methods.

2. Materials and methods

The present study is based on a one-week field research conducted in the village of Asiaber, located in northern Iran. The research team voluntarily traveled to the region, and data collection was carried out through direct observation, architectural surveying, interviews with local residents, and on-site investigation and damage assessment of buildings. During the fieldwork, the physical condition of the structures, their construction characteristics, and traditional building techniques were carefully documented and recorded. Semi-structured interviews were conducted with local inhabitants, particularly the elderly, to supplement the historical and indigenous knowledge. Upon completion of the field stage, the collected data were analyzed and compared with library resources and verified documents. The final analysis included a detailed examination of the structural characteristics of Zegali and Darvarjin walls, types of foundations (Pakuneh and Compacted earth), and methods of constructing sloped roofs. The aim of this process was to gain a deeper understanding of the technical and climatic features of the village's traditional architecture to assess the sustainability of these construction techniques against the environmental conditions of the region.

3. Enviromental and climatic Characteristics of the Region

Asiabar is a village in the Deylaman District of Siahkal County, located in Gilan Province. According to the 2016 census conducted by the Statistical Center of Iran, the population of Asiabar was 384. The houses in this village, like most houses in northern Iran, are generally built from wood and are typically one or two stories high. Wood is a naturally abundant material in northern Iran and has been readily available to the residents. The commonly used woods in this village include beech, yew, and alder. Yew (known locally as "Noonj") is particularly used in the foundations due to its superior resistance to heavy loads, moisture, and insects. The majority of the population's occupations are agriculture, animal husbandry, and beekeeping. According to the latest archaeological findings in the region, especially governmental seals, the history of human settlement in this area dates back to millennia before Christ. The average annual temperature of the county is about 15 degrees Celsius, ranging from 2.4 degrees in January to 25.1 degrees in July. This indicates that in this area due to the relatively low humidity and high altitude, the occurrence of severe cold is very possible. *(Book: Gilan - Group of Iranian Researchers)* Traditional Iranian houses were built in various ways considering the region's climate, culture, and local traditions. These houses were designed to be compatible with the environmental conditions and the needs of the inhabitants. One of the most important methods was the use of local materials. In northern Iran, most structures were made from wood and mud. Wooden structures are among the oldest construction methods in human history and have been used in different parts of the world since ancient times. The earliest uses of wood as a building material date back to when humans used branches and tree trunks to build shelters. Due to its natural properties, including lightness, flexibility, insulation, and renewability, wood has always been a popular building material. Wood has good resistance to compressive and tensile forces and can retain heat effectively. However, as previously mentioned, low resistance to fire and insects are the main disadvantages of wooden structures ("Introduction to Wooden Structural Systems and Their Advantages - Construction Encyclopedia"). In Gilan province, where the prominent climatic characteristics are moderate temperature, high humidity, and prolonged rainfall, housing must provide climatic comfort after basic needs such as shelter and refuge. Undoubtedly, residential buildings in Asiaber, like other rural buildings, are significantly influenced by the climate. To better and more effectively combat rain and snow, the roofs of houses are made sloped (four-sloped and two-sloped) to prevent moisture penetration from above. In the foothill areas of Gilan compared to the plain areas, relative humidity and rainfall are less, and the cold is more severe. Therefore, while maintaining sloped roofs, the walls become more enclosed, and semi-open and transparent spaces like porches around the building are absent, with only the main facade of the first floor having a semi-open space, often protected from the cold by full-length doors and windows. All principles of building orientation are influenced by climatic characteristics and aim for optimal use of favorable moisture-repellent winds while avoiding harmful winter winds, the region-specific hot wind, and slanting rain. In the physical and philosophical structures of traditional and local architecture of Gilan, the first floor or ground floor is built on a platform (usually 80 centimeters to one meter high) and typically on wooden structures (Pakoonah) to protect the spaces from ground moisture and dampness. The main facade faces southeast to avoid western winds and seasonal rains and to benefit the most of the summer breeze. Gilan province, part of the Alpine system and located on its central northern edge, has not yet reached real equilibrium in terms of tectonic movements and, like other parts of Iran, can be considered an unstable and vulnerable zone. Therefore, Gilan is among the high-risk seismic areas, and the occurrence of multiple earthquakes in this region is neither unusual nor unexpected.

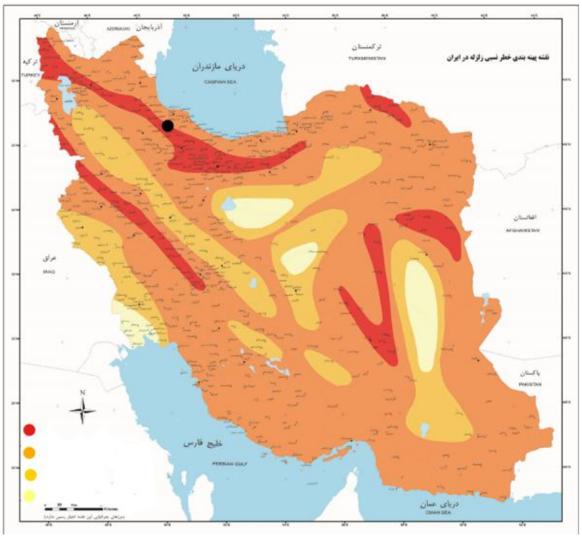


Fig. 1. Seismic zoning map of Iran and the location of Asiabar village

The 1990 Rudbar and Manjil earthquake can be considered the most significant earthquake in the area. This earthquake occurred at 00:30 Iran time (21:00 GMT) on Thursday, June 20, 1990, approximately 16 kilometers from Rudbar, centered in the village of Pakdeh and surrounding villages in Gilan province, causing extensive loss of life and property within a 100-kilometer radius. The earthquake's intensity caused at least four villages to disappear entirely along with their inhabitants. However, based on interviews with the elderly residents of Asiaber village, there were no casualties or complete structural collapses, but approximately 25 percent of the structures suffered partial damage. *(Asiaber Village Master Plan Revision Report)*

4. Traditional Construction Techniques in Asiabar Village

Asiabar houses consist of three main parts, foundation, walls, and roof. We will examine each of these components separately. The foundations were constructed in three ways: compacted earth, Pakuneh, and stone. In northern Iran, to prevent rising damp, most houses are built elevated above the ground. This is primarily achieved using the Pakuneh foundation, which allows for a raised structure, while a stone foundation can somewhat prevent direct contact between the moist soil and wood. However, compacted earth, remains in direct contact with the wood (Image3). The walls in Asiabar are of two main types: Zegali and Darvarjin. The Darvarjin wall is older and has become nearly obsolete, with only a handful still remaining in the village. The construction method involves placing a horizontal tree trunk on the compacted earth or stone foundation, followed by positioning the first wall trunk perpendicular to the first trunk. This process continues until the desired wall height is achieved, and then the gaps between the wood are filled with mud.

Fig. 2. Pakoune foundation and the way of its connection to Bone Nal

Fig. 3. A House constructed with Darvarjin Wall

The Zegali structure is typically built on a Pakuneh foundation. In this method, a trimmed horizontal trunk, known as Bone Nal, is placed on the Pakunehs. Then, several vertical trimmed woods are secured onto the Bone Nal. Thinner woods are then placed diagonally, horizontally, and cross-diagonally between the two columns and nailed to the columns. Finally, the wall is plastered with mud on both sides. Another method involves building two closely spaced rows of columns and filling the space between them with mud, which is referred to as double-layered Zegali.

Fig. 4. A Half-Built House with a Zegali Structure

Due to the heavy rainfall in northern Iran, the roofs of houses are made sloping. In this village, the roofs were also constructed with either two-sided or four-sided slopes. The primary material for the roof was originally Latte Sar, but over time, the villagers have replaced it with tin. To construct the roof, the main beams, Bam Dar, were first placed on the columns. Then, triangular or rectangular trusses were used to create the roof's slope, and finally, the tin or thin wooden boards (Latte) were placed on top as the covering.

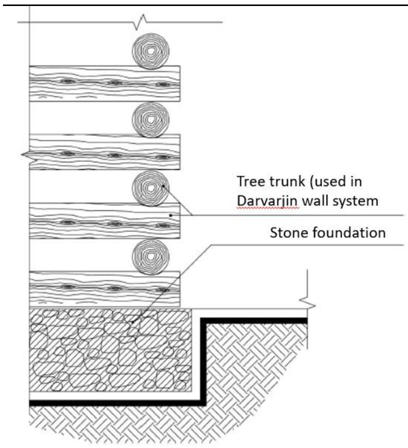
Fig. 5. Four-sided roof with Latte

Fig. 6.Tow-sided roof with tin

Table.1 Construction Details of Asiabar Village Houses   Source: (Identification of local construction techniques in the Asiabar village)

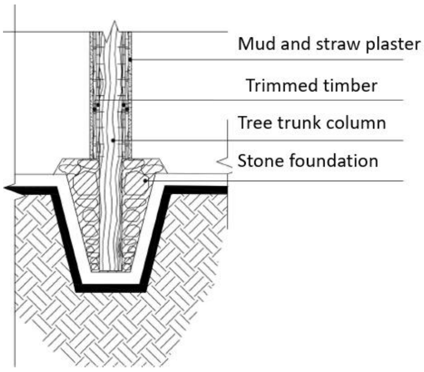
Wall	Foundation	Roof

Wall

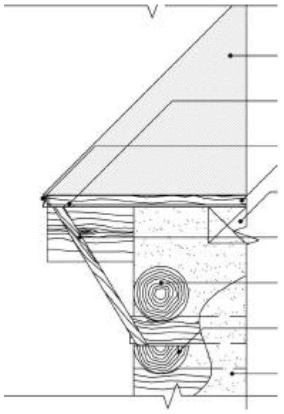


Darvarjin wall on stone foundation

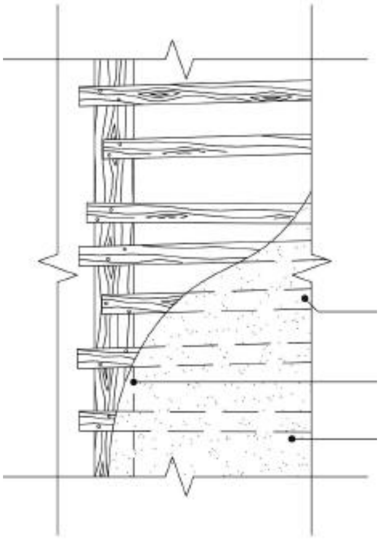
Foundation



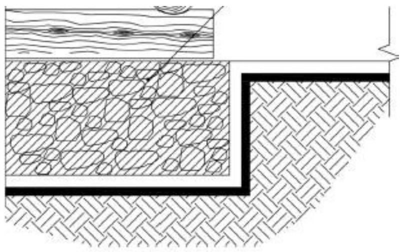
Roof



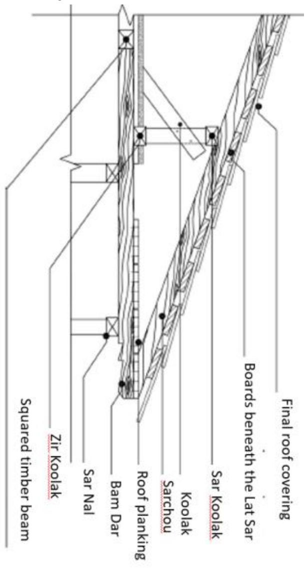
Connection method of Darvarjin to the roof



Horizontal Zegali

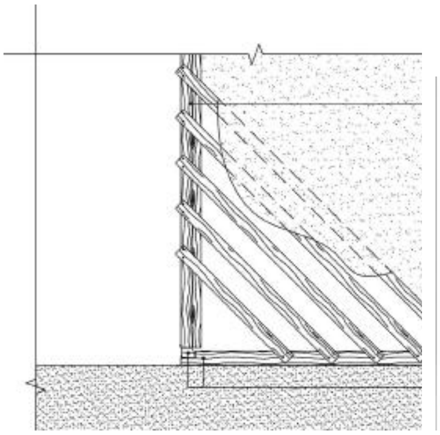
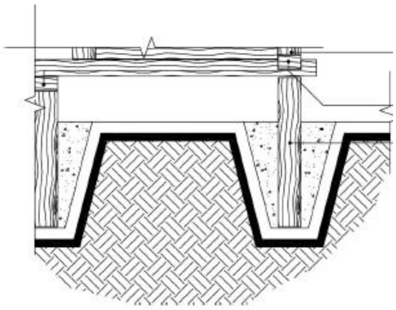
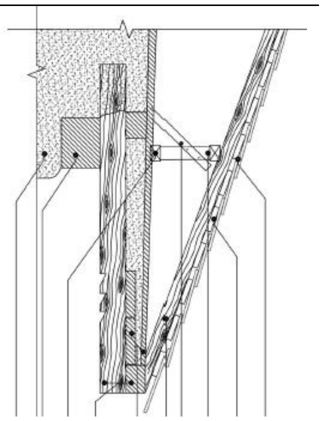
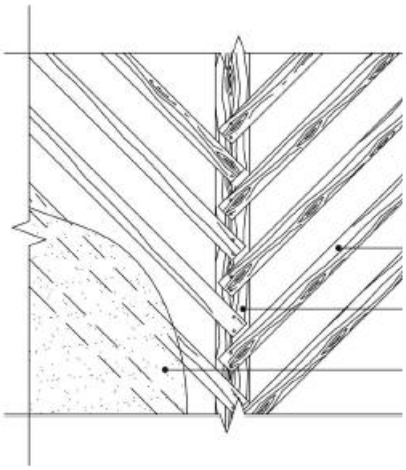
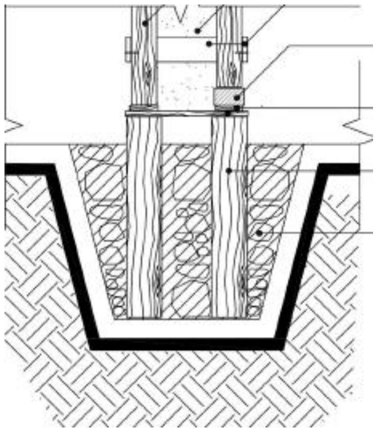
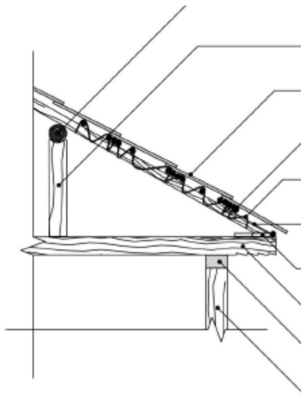


Stone Foundation



Latte Sar roof (First type)

Table 1 continued.

		
Diagonal Zegali	Pakouneh foundation	Latte Sar roof (Second type)
		
Double-directional diagonal Zegali	Pakouneh foundation	Latte Sar (Third type)

4.1. Construction Technique of House No. 1

Based on the interview conducted with one of the former apprentice builders from the mentioned village, the construction method of House No. 1, begins with digging pits approximately one meter deep and wide, locally referred to as sakat chah or sakteh chal. These pits serve as the foundation for installing the main vertical wooden posts called pakuneh. The pakuneh is typically made from durable tree trunks such as beech or yew (locally known as nonj). The wooden post is leveled in the center of the pit, then the surrounding space is filled with soil and stones. A process called Bako follows, during which the earth is compacted to secure the wood firmly in place. Once the Pakuneh posts are set, horizontal wooden beams known as Bone Nal are placed on top and nailed into the vertical posts. These beams support the main structural columns of the building, referred to as Geleh Sotoun, which are installed vertically and topped by another horizontal beam called Sar Nal. At this stage, the primary wooden framework of the building is complete up to the roof level. For the roof structure, main load-bearing beams called Bamdar—which serve as ridge beams—are placed over the Sar Nal beams. These elements are essential for maintaining structural stability, especially in snowy regions where snowfall can reach up to two meters. On top of the Bamdar, vertical wooden elements called Kulak are installed, forming part of the pitched roof truss. Over the Kulak, thinner horizontal wooden slats are placed, which help bind the four sides of the structure together and create a secondary lattice for the roof.

To form the pitched shape of the roof, inclined beams called Sarchou are added. In Latteh Bam (wood-planked) roofs, wooden planks are inserted intermittently into the Sarchu to lock them in place. The rest of the planks are laid overlapping each other without nails to prevent water penetration.

In the final roofing stage, additional wooden elements are installed perpendicular to the Sarchu. These elements differ depending on the roof type: if the roof is made of metal sheets, they are called Zir Halab, while in Latteh Bam roofs, they are known as Bigan. For bigan, simple round wood is used, whereas Zir Halab requires cut timber planks.

For wall construction, a technique called zegali is used. In this method, the space between the structural columns is filled with wooden elements to form a mold. A mixture of straw and clay, locally called shekeleh gel, is then poured into the mold. This method results in walls with thermal properties that keep the interior cool in summer and warm in winter.

4.2. Construction Technique of House No. 2

This building is the former local structure of Asiabar. The structure is rectangular or square in shape and was constructed using the Darvarjin technique. In this method, wooden beams called Varjin are placed alternately on top of one another. At the contact points where the beams overlap, shallow grooves were carved—locally referred to as Katoh—to allow better seating and stability of the beams.

On the southern side of the building, there is a balcony with windows also facing south. The windows were positioned in that direction to avoid the strong winds from the other sides. Another reason for constructing the balcony was to prevent snow from entering the openings. The preparation of timber beams and columns followed a three-step process: first shaping the cross-section with an axe, then refining it with an adze, and finally smoothing the surface using a hand planer.

The roof structure was also constructed using the Darvarjin method. According to one of the oldest architects of the village, when the height of the structure increased, the length of the beams decreased, resulting in a pyramid-like roof form. And he noted that the roof's outer covering, Darvarjin started above the main roof level and was built with thinner wooden elements. Experienced carpenters executed this roof type with four sloping surfaces.

4.3. Comparison of House No. 1 and House No. 2

Materials and Structural System:

• House No. 1: Combines timber and stone. Vertical wooden posts known as Pakuneh are placed in pits filled with soil and stones, which form the base. Horizontal beams are then installed on top of these posts.

• House No. 2: Constructed using the Darvarjin technique, where wooden beams are stacked alternately. The walls are made from timber filled with a mixture of clay and straw.

Moisture Management:

• House No. 1: The use of soil and stone at the foundation prevents capillary moisture from rising. This enhances the building's durability and resistance to moisture-related damage.

• House No. 2: Thanks to its elevated walls and wooden beams (such as Bone Nal) being kept above moist soil, the structure minimizes direct contact with ground moisture.

Roof Structure:

• House No. 1: The roof consists of load-bearing wooden beams called Bamdar, which support pitched roofs like Latteh Bam. Thinner wooden slats are placed above to complete the roof structure.

• House No. 2: Uses the Darvarjin method for roofing as well, employing stacked wooden beams. The roof has a pyramidal form with four slopes, constructed with thinner elements at higher elevations.

Ventilation and Daylight:

• House No. 1: Features south-facing windows that help reduce exposure to harsh winds and minimize snow entry into openings. This orientation also improves indoor light and airflow.

• House No. 2: Similarly, has balconies and windows facing south, providing comparable benefits in terms of ventilation and natural lighting.

Weather Resistance:

• House No. 1: In snowy regions, its stone and timber construction and sloped roof design effectively protect the building from heavy snow and harsh weather.

• House No. 2: With its thick timber walls filled with straw and clay, this house also performs well against moisture and snow, offering sufficient resistance to weather extremes.

5. Conclusion:

The comparative study of House No. 1 and House No. 2 in Asiabar village reveals two distinct yet equally resilient approaches to traditional architecture in northern Iran. While House No. 1 relies on a combination of wooden frames and stone foundations with a vertical post system, House No. 2 is characterized by the Darvarjin technique, where horizontal logs are interlocked to form the structural body. Both methods demonstrate thoughtful responses to environmental challenges such as humidity, seismic activity, and heavy snowfall. House No. 1 mitigates ground moisture through stone-filled pits, whereas House No. 2 elevates its wooden base to avoid direct contact with damp soil. Structurally, the diagonal Zegali system of House No. 1 may offer better earthquake resistance due to the inclusion of angled braces, while the Darvarjin structure provides strong thermal insulation and simplicity in construction. These vernacular techniques reflect deep-rooted local knowledge, adaptability, and sustainability, offering valuable lessons for future architectural practices, especially in culturally and environmentally sensitive regions.

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Design studio experiences in the context of a new building in a historic environment: the example of Fertek Hammam

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Abstract. The preservation of historical structures within the dense urban fabric and their continued existence in harmony with newly emerging structures is an important topic in today's urbanization debate.As part of the protection of cultural heritage, it is important to build additional modern structures to existing historic structures properly, to reuse historic structures or to preserve their original function and to continue their use in harmony with newly constructed groups of buildings.
In this study, the experiences of the architecture studio with the Fertek Hamam and its surroundings in the Fertek district of Niğde province were discussed. As part of the project course, the Fertek Hamam, which was in an unused state, was put back into use with the students of the design studio, modern additional structure proposals were developed and projects with different social functions were developed in the same building block as the hamam. Different usage scenarios were developed in the designs, and designs were developed to preserve the hamam structure and keep it alive by creating spatial relationships with new structures.
As a result of the study, proposals were made in relation to the construction of new structures in the historic environment, the conversion of historic structures and the construction of additional structures to historic structures. Firstly, the importance of historic structures for the preservation of the original collective memory was emphasized and that their original functions should be preserved or restored through a design that reflects their original functions, and that this can best be achieved through functional projects with social content and appeal to the general public. The study used examples to discuss the need to preserve the material characteristics of the historic structure, the development of design proposals for the recreational use of open and semi-open areas of the roofs, and the material characteristics of additional structures to be built on top of the historic stone structure. In addition, the study developed proposals that support and emphasize the historical and cultural richness in terms of residential culture and the use of public space in the Fertek district. Design proposals were made for the preservation and revitalization of the inactive hammam structure.

Keywords: Historic environments; Adaptive reuse; Appendices buildings; Cultural heritage

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1. Introduction

The Turks, who were called Anatolian Christians, lived in Anatolia, spoke Turkish and worshipped in Turkish and belonged to the Orthodox sect of Christianity, were called Karamanlis. The Orthodox Turks, who spoke Turkish and wrote Turkish with Greek letters, lived mainly in the areas of Konya, Karaman, Nevşehir, Kayseri and Niğde in Central Anatolia (Ekincikli, 1998) Karamanli Orthodox Turks, was a community the majority of which lived in the Cappadocia Region in Anatolia. Were subjected to the forced emigration to Greece as of May 1st, 1923 in accordance with the "Convention and Protocol relating to Exchange of Greek and Turkish People" signed on January 30th, 1923 between the Grand National Assembly of Turkey and the Greek Parliament (Öger,2013).

In the early periods of the Ottoman Empire, non-Muslims were granted rights, but their ability to construct new buildings was restricted in various ways. With the new world order in the late 18th and 19th centuries, non-Muslim minorities were granted more extensive rights so that they could better express their religion and erect new churches and other buildings. During these centuries, the Greek Orthodox erected numerous religious buildings in many parts of Anatolia. In Niğde, many churches are known to belong to the Orthodox Turks from Karamanli. Some of the churches were used as mosques to meet the needs of the Muslim population that settled in the city after the population exchange. Some of them are currently inactive. There are three hammams in Niğde that presumably belong to the Karamanlis. One of these bathhouses is the Fertek Bathhouse in the Fertek district.

Historical buildings carry a lot of information and historical memories such as construction techniques, material properties and socio-cultural values from the past into the present (Taştan and Manisa, 2019).

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On the other hand, cities are in a constant state of change. Historical structures that reflect the city's past may no longer be able to fulfill their original functions for many reasons, e.g. due to major social events such as war and migration, but also due to changes in living culture and living conditions, as well as changes in the types of structures needed by society. Today, one of the main topics of discussion is the evaluation of historic structures that are no longer able to fulfill their original functions, the preservation of which is of great importance for the transmission of collective memory to future generations and the survival of the city's identity. Freezing the historic structure in time and transforming it into an exhibit, defining a new function for the structure or adding modern additions while retaining the original materials and construction techniques of the structure are the main conservation methods used and discussed in today's architectural and planning world.

Within the framework of this study, the architectural design studio of Niğde Ömer Halisdemir University discussed the topics of new construction in historical surroundings, protection of historical buildings, conversion and modern additions to historical buildings specifically for the Fertek hammam, which was defined as the study area, and defined new functions for the use of the derelict historical buildings that meet the needs of the people in the neighbourhood. The study took into account the conceptual designs and ideas developed by the students during the 14-week workshop and developed design strategies for the construction of new structures in historic surroundings.

2. Study Area: Fertek Neighborhood

Fertek, which is 5 km away from Niğde city center, is one of the oldest settlements in the city (Fig. 1). It is a livable settlement area with vineyards, orchards and vegetation that includes different shades of green in the middle of the steppe. This historical settlement became one of the neighborhoods of Niğde with the legal regulations made in 2012 (Dinçer, 2008). Fertek neighborhood, which has a multi-layered settlement texture and dates back to the 3rd century AD, bears traces of the Roman, Byzantine, Seljuk and Ottoman periods (Dinçer, 2005). Narrow streets, stone houses with high ceilings and large courtyards, which exhibit traditional Anatolian architecture, reflect the architectural character of Fertek.

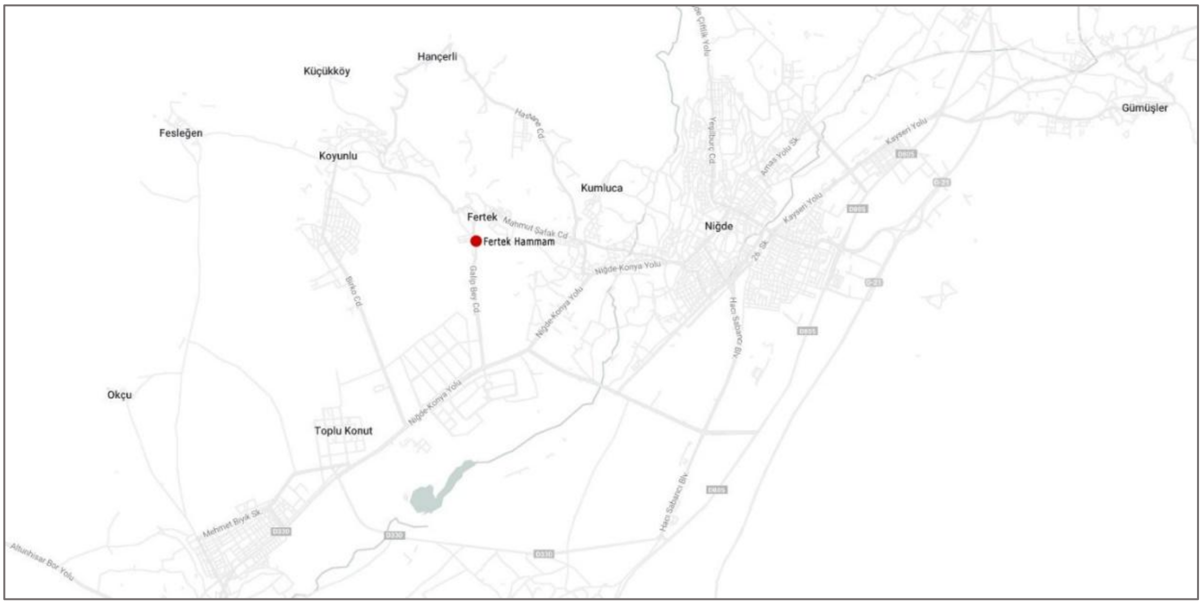

Fig. 1. Location of Fertek neighborhood (SnazzyMaps)

The Fertek district is home to important buildings such as churches, mosques, baths, underground cities, traditional houses and historic fountains (Fig. 2). The Fertek Church was converted into a mosque during the Republican period. The Fertek Bath, which is the subject of this study, was built in 1852-1853 and shows traces of Byzantine-Ottoman architecture, but is currently not in use. These buildings belong to the Turkish-speaking Orthodox Christians known as Karamanli. The Karamanli population emigrated to Greece as part of the Turkish-Greek population exchange in 1924, and Turkish immigrants from various parts of Anatolia settled in their place.

Fig. 2. Neighborhood texture in Fertek (Taştan,2025)

3. Fertek Hammam

The Fertek Bath is one of the buildings that have survived to this day from the Karamanlis, who immigrated to Greece as part of the population exchange. It is located on Hüseyin Avni Göktürk Boulevard, which connects the Fertek district with Bor Street. The bath is located on the border of the original neighborhood, in the area called "Hamamarkası". For this reason, its immediate surroundings are surrounded by newly developing residential areas. The structure, which is located on an area of 1650 square meters, is within the protected area boundary determined by the decision of the Kayseri Regional Cultural Heritage Conservation Authority dated 24.02.2022 with the number 5812. Within the scope of the study, two adjacent plots with an area of 430 square meters and 520 square meters together with the area where the bath is located were selected as the project area (Fig. 3).

Fig. 3. Location of Fertek hammam (GoogleMaps).

The inscription written in Karamanlidika indicates that the bathhouse was built in 1853 during the reign of Sultan Abdülmecid I. It was built on a rectangular ground plan on a slightly sloping terrain in a north-south direction about 2 meters below street level. Due to the street level, the bathhouse has an entrance that gradually slopes downwards as the ground level is lower (Ekiz, 2014).

Fig.4. Roof system of the Fertek hammam (Taştan, 2025)

The hammam is a domed building made of carved stone and bears the characteristics of Byzantine-Ottoman architecture (Dinçer, 2008). The Fertek Bath, whose rooms are arranged from south to north as a (soyunmalık) changing room, (ılıklık) warm room and (sıcaklık) hot room, was actively used until 1990. However, it is currently unused. The original plan of the structure is generally well preserved and has survived to this day. Extensions were built around the building over time, which have no historical value. The building materials used in the structure were mainly ordinary carved stone, a small amount of marble and a very small amount of brick (Ekiz, 2014). The (soyunmalık) changing room part of the building is covered with a dome resting on an octagonal drum. other areas are covered with skylights that protrude slightly from the ground (Fig. 4).

4. New Building Design in Historical Environment: a constitutive theme in Architectural Design Studio

This study deals with the strategies for the design of new buildings in historical environments developed within the framework of projects carried out with second-year students of the Architecture Department of the Faculty of Architecture at Niğde Ömer Halisdemir University. The main purpose of the 14-week architectural design studio is to create a discussion environment for students on topics such as the reuse and preservation of abandoned historical structures, the design of new buildings in historical environments, the design of additions to be made to historical structures and to develop students' awareness of historical structures. During the process, various literature research and analysis related to the field of study were conducted. As part of the course, an interim jury and a final jury were conducted with the participation of the course instructor and other academics and the students' work was evaluated. During the process in which modern protection, conversion and new building design approaches were discussed, theoretically applicable, conceptual idea projects were carried out in compliance with basic architectural protection rules. During the workshop process, five different design strategies were applied in the design of the projects, namely preserving the original function, adaptive reusing, building a modern extension, interventions that preserveor refer to the collective memory, and taking into account the needs of the region and the society to which it belongs.

4.1. Preserving the original function of the building

The most appropriate use of a historic building is to keep it alive by ensuring its continuous maintenance (Tunçoku, 2004). Preserving the original function of the building in modern times and adding various new functions that meet the needs of people today is the most efficient way to preserve a historical building. The bathhouse, that has served the Fertek district for years, is currently not in use. Ensuring that the bathhouse continues to fulfill its function today will keep not only the building but also the bathhouse culture alive. During the workshop process, some students preserved the original function of the bathhouse and supplemented this function with functions such as a spa, physiotherapy center, gym and day care center (Table 1.).

4.2. Adaptive reuse of the building

As a result of changing living conditions over time, most historic buildings are no longer able to fulfill their original functions. Due to the value, they have, their adaptive reuse offers not only environmental and economic, but also social and cultural benefits (Taştan and Manisa, 2019). In architecture, conversion or adaptive reuse is defined as the transformation of a building that can no longer fulfill its original function for some reason to fulfill another function. Adaptive reuse is a process of preserving the existing structure as much as possible while developing it to meet current user needs (Latham, 2000). Identifying the heritage values is an important factor in the decision-making process that directly affects the decision on the new function. The needs of the district should be defined to determine the most appropriate function for the heritage building. The heritage buildings should be evaluated in the context of the whole district (Mısırlısoy and Günce, 2016).

4.3. Adding a Modern Annex to a building

Contemporary conservation theory aims to preserve historic buildings primarily in their original function. If this is not possible, it provides for equipping the building with a contemporary function and intervening with methods that do not damage the building and with modern materials. The most important parameter of the contemporary conservation approach, which aims to intervene in the building in a minimal way, is the inclusion of approaches that separate the features of the period of origin from the original building by using architectural variables such as form, color, texture and material and not misleading the public. (Yapan and Büyükmıhçı, 2023). Any intervention in a historic building should be reversible without damaging the building. This strategy is particularly important for temporary sections or exhibition areas that are built inside. The materials used in new additions should be used in a language that respects the character of the historic building without imitating it. For interventions and extensions, the original form and materials of the historic building should be preserved and the necessary repairs and reinforcements made with a minimum of intervention; the newly added spaces should be such that they do not affect the existing building and can be easily restored to its former state.

4.4. Interventions that protect/reference the collective memory

The preservation of historic buildings in a way that reflects the characteristics of the period in which they were built, such as construction techniques, materials and living culture, contributes to the continuity of collective memory by allowing memories to be revived in social memory (Bandarin, Oers, 2012). It is therefore to be expected that any conservation intervention will contribute to the preservation of this collective consciousness.

4.5. Consideration of the needs of the region in which the building is located and the society to which it belongs

The heritage buildings should be evaluated in the context of the whole district (Mısırlısoy and Günce, 2016). Regardless of whether historic buildings are re-functioned, preserved with their original functions or treated together with new modern additions, the most important design element is that the building is treated in a way that serves the neighborhood and the society it belongs to. Buildings gain meaning when they are preserved by being included in daily life and not frozen in time like a museum object. Therefore, when dealing with a historic building, not only the physical but also the social needs should be considered. As a result of the studies carried out in the architectural design studio, the above-mentioned methods and design strategies were applied in connection with the Fertek Hamam and various designs were realized. During the design process, the question of whether the original function of the hamam should be preserved, what function the new building should have and how it should relate to the historical building were the main design decisions (Table 1).

Table 1. Projects and design decisions made in the architectural design studio.

	Project Name	Function of Historical Hammam	Function of New Building	Design Approach
1	Fertek Library and Coworking Center	The hammam was re-functioned as a library.	Co-working spaces and offices for rent.	The modern glass building, which was added to the historic bathhouse structure, created the entrance area for the library, café and social areas were created.
2	Fertek Çınaraltı Social Facility	Its original function has been preserved and it was intended to be used as a neighbourhood hammam.	A social facility with services such as workshops, libraries, cafes and gyms that can be used by the local people, especially the elderly and retired people.	While preserving the bathhouse culture, it is also aimed to preserve the culture where the elderly population socializes by drinking tea and coffee under the plane tree.
3	Fertek Spa and Natural Treatment Center	Its original function has been retained and it is to be used as a bathhouse with an integrated spa center.	Modern annex creating a sunken courtyard with spa, massage and physiotherapy functions.	The bath culture has been preserved by blending it with modern needs.
4	Fertek Elderly Care Center	Its original function has been preserved and it was intended to be used as a neighbourhood bath.	A centre where the elderly and people in need of care can receive health services, socialize and stay for a short time.	In addition to the recreation areas in the courtyard, which were created by the historic hammam and the new building, a winter garden with a modern glass extension was added to the hammam's wall.
5	Fertek Book Bazaar	The bathhouse building has been converted into a workshop and exhibition hall where traditional arts such as marbling are displayed.	It includes social areas such as workshops, bookstores and cafés.	The terrace roof of the restored hammam was used as a temporary exhibition and event area, allowing users to experience the building in a variety of ways.

Table 1. continued

6	Fertek Healthy Living Center	The original function of the bath has been preserved.	It consists of psychological support, sports and healthy life units.	The social spaces were designed by creating a common courtyard with the hammam's structure.
7	Fertek Youth Center	The structure of the hammam has been converted into a museum that reflects the bathing culture.	It includes socializing areas with a cafe, gym and swimming pool.	The social spaces were designed by creating a common courtyard with the hammam structure.

5. New Building Design in Historical Environment: experiences from Architectural Design Studio

5.1. Architectural form experiments

During the workshop process, various form experiments were conducted that relate to the architectural features of the historical building and bathing culture. One of these is the mass experiment, which was carried out using the example of the polygonal supporting wall supporting the dome in the "soğukluk" area of the hammam. In the study, in which workshop units with independent entrances and service units larger than the workshops gradually rise, semi-open areas are created in places and open areas that will function together with the historic structure are designed (Fig. 5)

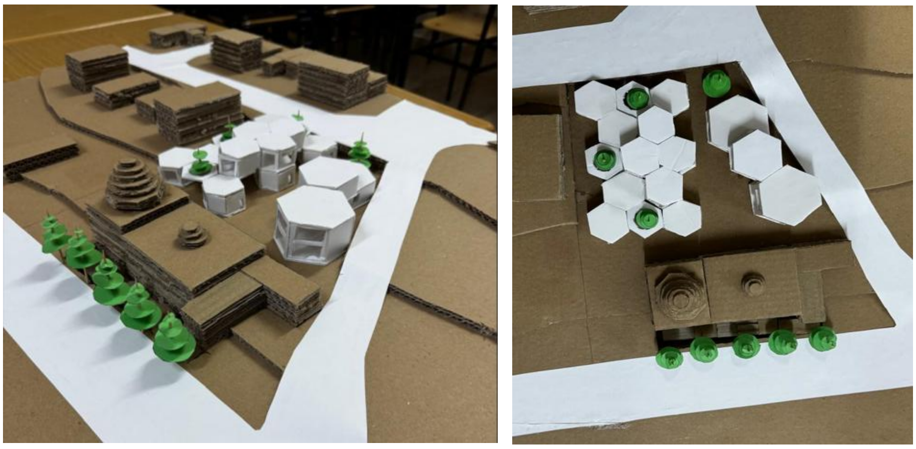

Fig. 5. Samet Bakır's attempt at architectural form.

5.2. Creating an inner courtyard

The courtyard not only provides a degree of privacy, but also forms a natural barrier for noise control. The use of a courtyard is considered an excellent solution as it creates a quiet area where various activities can be carried out away from noise (Beyoğlu, 2019). In public buildings, courtyards can be used as public gardens with controlled access and can be used by everyone. In the design proposals developed during the workshop process, the new buildings are not directly adjacent to the historic bathhouse, but are connected to a courtyard or transitional area, maintaining the distance and creating a visual connection with the historic building. In the courtyard, shaded areas, open space arrangements, seating and walkways were created and a lively intermediate area was designed between the historic bathhouse building and the social facility (Fig. 6).

Fig. 6. Project models of Yakup Tekin and Rıdvan Ercan.

Another student, Rulla Cellul, designed the courtyard in such a way that her spa project created a sunken garden 3 meters below ground level, preserving the original function of the historic bathhouse. This courtyard, which offers a high degree of privacy, combines the spa and bathhouse experience with tranquillity (Fig. 7).

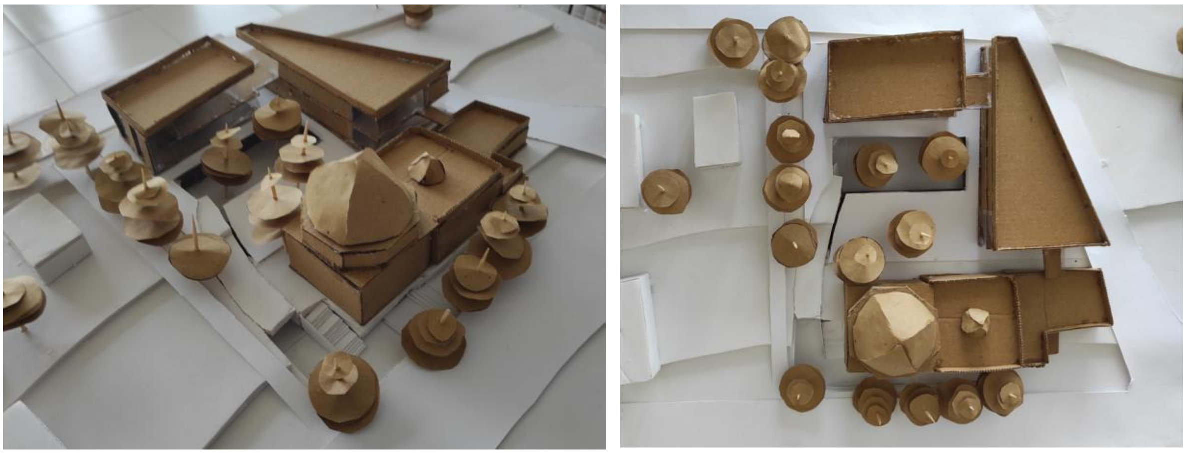

Fig. 7. Project model of Rula Cellul.

5.3. Touching the Historical Structure

The oven, the water tank and the 'sıcaklık' section of the historic hammam are covered with a patio roof. The wide roof of the hot section offers a perfect view of the dome of the cold section. The upper covers of these units, which rise in steps, are easily accessible via stairs. Spaces with various functions, such as an exhibition hall and a café, were designed as part of the project and are connected to this useful terrace area from the additional structure (Fig. 8). Historic buildings, which are interesting exhibits with their materials, construction techniques and façade details, are kept alive and used by people in some way, and a design that allows people to touch and look closely at them helps to create the desired natural atmosphere.

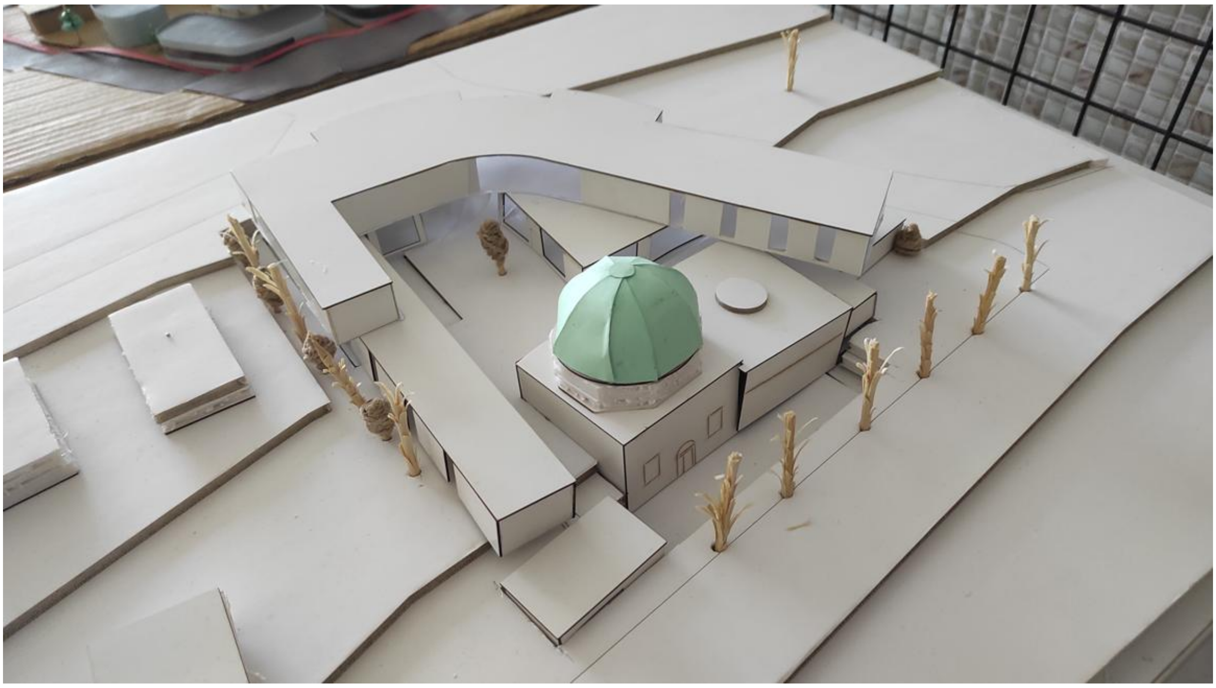

Fig. 8. Kübra Arslan's project model.

Besmele Dillo carried out a further study in which the upper cover of the oven, water tank and other units was achieved with a bridge and an open space design. The structure creates a courtyard by surrounding the bathroom and access to the courtyard is from street level, with the drains on the first floor. In addition, a winter garden made of a steel structure and completely glass facades were designed in the project, which serves the courtyard and uses the stone wall of the historic structure as a 4th Surface (Fig 9).

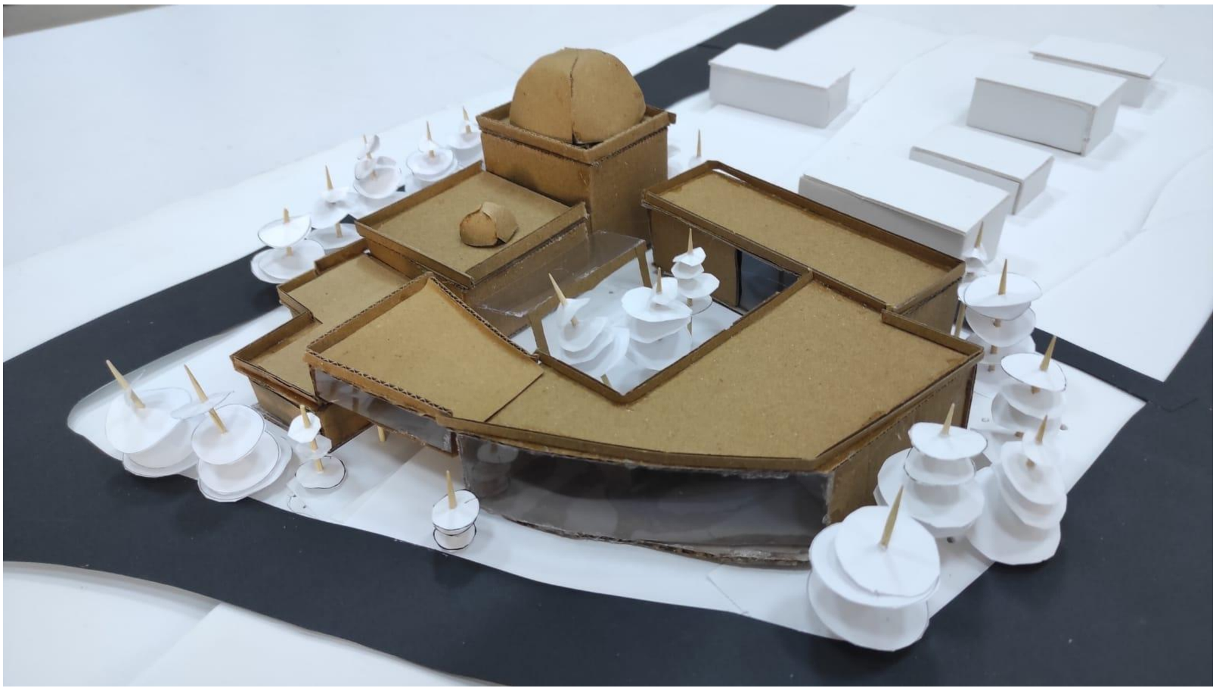

Fig. 9. Besmele Dillo’s project model.

5.4. Adding a Modern Annex

In Tunahan Günaydın’s project to convert the historic bathhouse into a library, the new structure includes shared workspaces and offices. In this project, a glass extension was added to define the entrance to the bathhouse and create a meeting area and open areas of the café. The annex, designed in relation to the café and office areas in the basement, is completely demountable and is made of steel and glass compatible with the stone, the original building material of the bathhouse (Fig. 10).

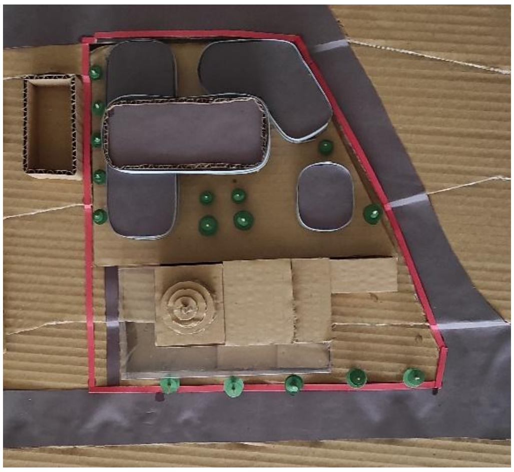

Fig. 10. Tunahan Günaydın's project model.

5.5. Keeping the collective memory alive

The Fertek bathhouse, which belonged to the Orthodox Turks known as the Karamanlis, bears many traces of collective memory to the present day. The bathing and bathhouse culture of the Karamanlis, who left the region as part of the population exchange, and the activities they carried out in the bathhouse should be kept alive by designing the building to fulfill functions such as an exhibition hall and a bathhouse museum. The use of the bathhouse, which was known to have been in operation until 1990, in its original function was also seen as another way of keeping the collective memory alive. One of the most important parts of daily life in the Fertek neighbourhood, where the elderly population is now densely packed, are the tea houses around the neighbourhood’s historic church and the seating areas under an associated tree. Muhammed Dalkılıç's project made reference to the culture of socializing under trees and designed the social facility around a plane tree. The plane tree was placed in the center of the conservatory to protect it from the harsh Niğde climate and create a semi-open area at any time of the year (Fig. 11).

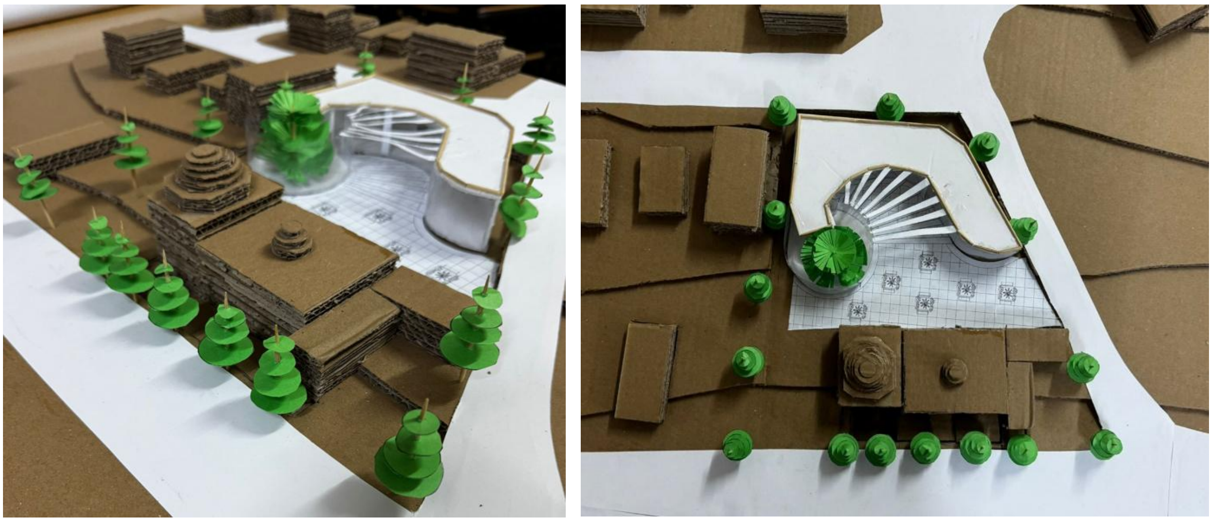

Fig. 11. Muhammed Dalkılıç's project model.

5.6. Ensuring environmental and social sustainability

When historic buildings are designed as spaces that are accessible to all people in society without financial constraints and where they can spend time, they go beyond being a shared value of society that needs to be protected and become meaningful and useful spaces for all. Transforming historical buildings into spaces that are accessible to all contributes to social sustainability. Azat Altın's project is characterized by sports areas, psychological care and health stations that can be used by the residents of the neighbourhood. The project, which retains the original function of the bathroom, includes design strategies aimed at environmental sustainability, such as a winter garden and the use of panels that generate electricity from solar energy (Fig. 12).

Fig. 12. Azat Altın's project model.

6. Conclusions

This study discusses design strategies developed to preserve the historic value of the vacant Fertek Bathhouse and revitalize it in a way that meets the needs of today's society, and draws conclusions for the protection of historic structures in similar situations.

- Preserving the original function of the structure: When protecting historic structures, the original function of the structure should be prioritized. When preserving the original function, it is important to maintain the structural and design integrity of the building. Instead of making structural interventions to maintain the original function, other solutions should be developed for the additional spaces required.
- Adaptive reuse of the structure: When reusing a structure that can no longer fulfill its original function, the original function of the structure, its historical value, the needs of the environment in which it is

located and the environmental, cultural, physical, economic and social conditions of the structure should be comprehensively analyzed.

- Adding a modern annex to the building: If a modern annex is to be added to a building of historic value, the principle of minimum impact should apply first and any addition should be designed to be reversible. The new building should be compatible in material and texture with the existing building, not imitate it in any way, but be visually and physically in harmony with the existing building. The façade, scale, proportions and finishes should be designed to match the existing structure.

All interventions in historic structures should take into account the social and physical needs of the environment in which they are located and the characteristics of the structure. It should be ensured that a historic structure is transformed into a space that can be experienced by all sections of society without physical or social barriers. In this context, the development of sustainable conservation and conversion strategies, taking into account social, economic and physical aspects, is becoming increasingly important.

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Conceptual evaluation for the Integration of historical railway stations into high speed railway systems in the perspective of sustainable development goals

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Abstract. The railway history of Türkiye can be analyzed under three headings: Pre-Republican period, Republican period: 1923-1950 period and the post-1950 period. The post-1950 period has different stages of development. Between 1950-1980, the construction of railways remained in the background as highway transportation gained momentum. In the 2000s, the integration of high-speed rail technology into national policy gained pace. The growing importance of high-speed railway transportation since the 2000s can be linked to the concept of sustainability. Sustainable development is one of the prominent concepts in the report "Our Common Future" (Brundtland), published by the World Commission on Economic Development (WCED) in 1987. In 1992, the Rio Earth Summit was held in Rio de Janeiro, the main outcomes of which were Agenda 21 and the establishment of the Commission on Sustainable Development. All these developments can be characterized as factors that accelerated the introduction of the concept of sustainable development into the agenda of international and national policies. Historic railway station structures have great importance in terms of providing economic and environmental benefits, as well as deep cultural and social ties to national history and urban identity. The continuous use of station buildings, with necessary maintenance and renovation interventions, offers many advantages in terms of reducing the consumption of energy and raw materials required for the construction of new buildings, reducing carbon emissions, preserving culture and history layers belonging to urban identity. It is clear historic station buildings have an critical role in achieving sustainable development goals. With the development of railway technology, historic railway lines and station structures have entered a process of transformation in line with modern technology and requirements. This global transformation is also having an impact at the national level. In this context, the issue of adapting historic station buildings to high-speed train technology has gained importance. Within the scope of this research, examples of international and national approaches to the integration of historic station buildings with high-speed train buildings will be examined. Then the selected examples will be evaluated conceptually in the context of sustainable development goals.

Keywords: Histotric train stations; Adaptive re-use; Sustainable development; Conservation of cultural heritage

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1. Introduction

Railway transport has been one of the most important carriers of the technological and social transformations that accelerated with the industrial revolution on a global scale. Since the mid-19th century, railway lines and related station structures have not only shaped transport networks, but also deeply affected the physical structure, economic development and social dynamics of cities. Considering the railway history in Türkiye after the proclamation of the Republic, three main development phases can be defined: between 1923-1950, between 1950-2003 and after 2003. These periods are closely related to the economic, political and social changes and technological developments in the country. In the early Republican period (1923-1950), two significant policies were implemented, which had a considerable impact on the development of railway transport. The first of the aforementioned measures was the nationalisation of railway lines that were previously controlled by foreign capital. The second objective was to establish the essential transport infrastructure in regions lacking railway lines and integrating the existing network with the new infrastructure. The objective of this initiative is to establish an

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independent transport network that would facilitate efficient connectivity between the eastern and western regions of the country (Yalçın, 2024 as cited in Ekizoğlu, 2012).

Especially after 1950, with the prioritisation of road transport, railway construction activities remained in the background and railway investments followed a stagnant course. However, since the 2000s, the integration of high-speed train technologies into national transport policies has accelerated and a renewed interest in railway transport has emerged (Pektaş, 2017). This process is also overlapping with the gaining importance of the concept of sustainability on a global scale. The process, which started with international studies such as the Our Common Future (Brundtland) Report published by the World Commission on Economic Development (WCED) in 1987 and the 1992 Rio Earth Summit, has placed sustainable development at the centre of contemporary development goals. In parallel with the developments in the international agenda, the concept of sustainability has started to be discussed at the national level in terms of environmental impact.

In the 7th Development Plan prepared in 1995, attention was drawn for the first time to the negative environmental impacts caused by the transport sector. The need to increase the importance given to railway transport in public investments in the transport sector in Türkiye was emphasised for the first time in the 7th Development Plan, and the concept of sustainability was officially included in the 8th Development Plan prepared in 2011 (Zeren, 2021). Railway transport, which is a sustainable and efficient method in terms of environmental protection policies as an alternative to road transport, which is dependent on fuel consumption with high carbon emissions in both global and national transport policies, comes to the forefront with the development of high-speed train technologies (Candan Demirkol & Gülpınar, 2023).

Railways are socio-technical systems morphologically composed of 'social' and 'technical' elements. These elements cannot be separated from each other. A holistic approach is needed to properly analyse the historical significance of railway systems (Coulls et al., 1999). As an industrial heritage, railway structures have a strategic importance as social spaces that stand out in the city identity with the technical infrastructure they offer in the field of transport. Evaluating the changing technical infrastructure and social conditions together with technology is of great importance for the conservation of these heritage sites. In the period from the 1950s to the 2000s, the problem of the existing railway structures becoming idle and losing their importance by losing their function due to the prominence of road-based transportation and the effect of modernisation has started to be discussed. Railway structures, which are considered under the title of industrial heritage, came to the forefront in the 1970s as an element of cultural heritage (Kösebay Erkan & Ahunbay, 2008 as cited in Ede & Çelen Öztürk, 2024).

Since 2003, conventional railway lines and station structures, where national passenger transport services are provided, have been transformed in line with modern needs. Construction of new lines and station structures serving high speed train technology has gained momentum. In the 2024-2028 TCDD Strategic Plan, the vision of using renewable energy resources to contribute to a cleaner world and implementing sustainable practices to minimise the negative environmental impacts of railways has been adopted. Within the definition of this vision, the concepts of economic and environmental sustainability come to the fore. The development of different design models in order to carry out applications without damaging the buildings with historical value is among the targets included in the plan (T.C. General Directorate of State Railways, n.d.). This approach can be associated with the cultural dimension of sustainable development. The construction of new technological transport infrastructure brings along a number of debates. In the period from the 1950s to the 2000s, the prominence of road-oriented transport and the inactivity of existing railway structures due to the effect of modernisation and the loss of importance by losing their function have started to be discussed. This situation brings the problems regarding the preservation of the national railway heritage to the forefront of the agenda of contemporary conservation debates. TCDD does not have an effective inventory of its cultural heritage building stock. Documents, photographs, maps or drawings related to the history of these buildings are not collected in a single archive. The absence of an effective archive system for the protection of railway heritage creates a disadvantage for the protection of this heritage. Problems such as the demolition of existing buildings if deemed necessary and the loss of importance of existing historical buildings by becoming dysfunctional with the commissioning of new buildings come to the agenda (Kösebay Erkan & Ahunbay, 2008). In addition, although the strategies developed include the development of innovative designs for the protection of historic buildings and the expression of sustainability, an effective conceptual framework for the planning and implementation of these designs has not been defined.

The 17 universal goals and 169 objectives determined as a result of the United Nations' efforts to include sustainable development in country policies and to create global goals are a guide for multilateral and collaborative development strategies at the international level (Gedik, 2020). The Sustainable Development Goals (SDGs) published by the United Nations in 2015 are planned to be achieved by 2030 (United Nations, 2015). The strategic plans and programmes developed to achieve these goals prove the power of these goals to take action. These goals can be defined as a dynamic action tool that covers multidimensional goals such as environmental protection, economic development, social justice and cultural heritage protection. The integration of historic stations with new transport systems requires the development of effective approaches that are environmentally, economically and socially sensitive to the preservation of cultural heritage, modern living conditions and human needs. Objective, versatile and binding SDGs can be used as a tool for the development of these effective approaches.

Within the scope of this research, examples of international and national approaches to the integration and re-functionalisation of historical station buildings with buildings built for high-speed railway lines are examined. This examination aims to develop a conceptual perspective based on the evaluation of the selected examples through the concept of sustainability.

2.Methodolgy

Qualitative research methods were adopted in this study. Within the scope of the study, national and international examples of the integration and re-functionalisation of historical railway stations with high speed train lines were examined through literature and archive review. In the literature review, primary and secondary sources such as academic articles, reports, project documentation and relevant policy documents were utilised. During the literature review, the history of railway development in the Republic of Türkiye was firstly researched. In order to facilitate the research and evaluation stages, the history of railway development was handled in periods. Accordingly, three main development phases were defined as between 1923-1950, 1950-2003 and after 2003. Then, focusing on the concept of railway heritage, literature and archive researches were conducted on the studies on the conservation of historical station buildings. In the next step, literature researches were conducted on the historical development of the concept of sustainability and sustainable development. Literature researches were carried out to analyse the place of railway transportation and cultural heritage conservation approaches in sustainable development. International and national examples for the integration of historical station buildings and high-speed rail transport have been analysed using literature and archival documents. In the next methodological stage of the study, the examples analysed were conceptually evaluated on the axis of sustainable development. In the last stage, all the findings obtained are evaluated and included in the conclusion section.

3. Evaluation of the integration of historical railway stations into high speed railway systems in the perspective of sustainable development goals

In this chapter, the integration of historical railway stations, which have been shaped within the framework of the development process from the early periods of its history to the present day, with high-speed railway (HSR) systems is evaluated in the context of sustainable development goals. In this context, the historical development of the Republic of Turkey's railways is discussed. Subsequently, an evaluation is conducted of international approaches to the importance of railway structures as cultural heritage. Furthermore, with reference to the architectural, technical and socio-cultural characteristics of railway structures, the protection of these structures, ensuring their functional continuity and integrating them with modern transport systems, is discussed within the scope of the United Nations Sustainable Development Goals.

Finally, in this framework, national and international examples are analysed to evaluate the technical, functional and conservation-oriented challenges encountered in the process of integrating historical stations with high-speed train technologies.

3.1 Historical development of Turkish Republic railways

Railway policies of the Republican period are generally considered in three main phases. The first period is the period between 1923-1950 when the railway had a priority position in transport systems. The second period covers the years 1950-2003, when Türkiye started to intensify its relations with the United States of America within the framework of the Truman Doctrine in 1947, which led to a change in the direction of transport policies and highway investments came to the forefront. The third period is the period in which the restructuring process in railway transport started as of 2003, high speed train projects were prioritised at the state policy level and railways were repositioned as a strategic transport model (Ekizoğlu, 2012).

The railway policy effective in the period between 1923-1950 was carried out in line with two main objectives. The first one was to build railway lines covering neglected regions as well as developed centres and to organise the entire transport infrastructure through an interconnected network system. In this way, it was aimed to support national unity and economic development. Secondly, the nationalisation of railway lines inherited from the Ottoman Empire and controlled by foreign companies was adopted as a strategic step towards the nationalisation of transport infrastructure (Öztürk, 2009). In the Early Republican period, political and strategic priorities were decisive in the approaches towards railway enterprises. In this period, the size of the station buildings was planned by taking into account the population and importance of the settlement through which the line passed. The buildings constructed in the 1920s have elements such as wide eaves, arched windows and tile decorations reflecting the architectural understanding of the period. The 1926 Ankara Gazi Station and the 1912 Adana Station are examples of this architectural approach. In the 1930s, the simple and massed forms of modern architecture were blended with an understanding symbolising the authority of the state. Ankara Station, designed by Şekip Akalın in 1937, and Afyon Station in 1939 are among the buildings of this period, where prismatic masses add mobility to the façade (Sezginalp & Sezginalp, 2021). According to the Truman Doctrine, which developed during the Cold War period after World War II, Türkiye was included in the Marshall Plan in 1948. In order to benefit from the Marshall Plan, Türkiye was required to accept a number of conditions. As a result of these conditions aimed at increasing the economic volume of private enterprises by reducing public entrepreneurship in the economy, it was put forward not to establish heavy industries such as iron and steel and heavy chemistry (Öztürk, 2009). This situation started the process that led to the railway lines being put into the background due to the emphasis on highway investments.

From 1950 to 2003, the importance given to railways gradually decreased. Road transport was encouraged through Marshall Aid and highway construction gained momentum. As a result of the road-oriented transport policies implemented in this period, highways took the first place among transport systems. Accordingly, the number of motorised vehicles increased rapidly in the following years. A completely foreign-dependent automotive industry was established for the necessary fuel and spare parts needs (Pektaş, 2017). In the 1996-2000 7th Development Plan prepared in 1995, attention was drawn for the first time to the negative environmental impacts of the road-based transport sector (Zeren, 2021). The increase in the use of motor vehicles has brought along the problems of excess fuel consumption, environmental pollution, accidents and traffic congestion in urban transport in Türkiye (Prime Ministry State Planning Organisation, 2010).

The EU harmonisation process has directly affected Türkiye's national policies, particularly in the field of transport. The development of the physical and economic infrastructure of the transport sector, which is directly related to the revitalisation of sectors such as trade and tourism, has become a priority issue. This priority status has directly affected the development plans prepared by the state, which also include transport policies (Zeren, 2021). In the Long Term Strategy 2001-2005 and the Eighth Five-Year Development Plan, the main objective is to strengthen the role of railway operations in the country's transport system by making them compatible with market conditions, commercially oriented and efficient.

With the effect of all these developments, 2003 was a turning point in railway transport and high speed train technology was included in national transport policies. In this way, railways were adopted as a priority transport model again as a state policy. In addition to Ankara-Istanbul and Ankara-Konya High Speed Train Projects, cooperation was established between the central government and local administrations for the development of urban rail public transport systems. In this context, large-scale urban rail transport projects such as Marmaray in İstanbul, Ege-ray in İzmir and Başken-tray in Ankara have been implemented (Karaman, 2010 as cited in Ekizoğlu, 2012). In the Ninth Five-Year Development Plan for 2007-2013, it is stated that the existing railway infrastructure is not suitable for high speed and high quality service between large populated cities. Within the scope of improvement works, restructuring of railway line and station structures to make them suitable for high speed train operation has been brought to the agenda (Ekizoğlu, 2012).

In the 19th century, train terminals built in many important cities of Europe attracted attention with their wide-span railway halls reflecting the developing engineering possibilities of the period. Today, these buildings are facing a 'station renaissance' process; some of them have been modernised and adapted to high-speed train (HSR) systems. In the last two decades, in line with the goals of revitalising city centres and expanding HSR networks, large-scale new generation station structures with multifunctional programmes have been built. These stations stand out not only as transport infrastructure but also as monumental structures within the urban space. Ankara HSR Station and Konya Selçuklu HSR Station, which have been commissioned in Türkiye in recent years, are among the local examples of this new generation of multifunctional and large-scale station buildings (Zeren, 2021).

3.2. Importance of railway structures as cultural heritage

The UK, which is at the forefront of the development of railway technology, has many examples in terms of the construction and preservation of railway structures. Therefore, analysing how railway heritage is handled in England is advantageous for studies in this field. Until today, railway heritage has not received the attention it deserves, including in the UK. The closure of many railway lines in the 1960s when coal mines became dysfunctional, and the structures lost as a result, have led to an awareness of railway heritage in the UK (Kösebay Erkan & Ahunbay, 2008).

The process of including railway infrastructure within the scope of cultural heritage initially encountered two main obstacles. Firstly, railway remains were considered as ordinary and functional infrastructural elements for a long time; this situation caused both their cultural and technological values to be insufficiently recognised. Secondly, due to this perception, the lack of an effective legal framework or regulation for the protection of railway structures has made the protection of these structures difficult. The acceptance of the concept of industrial heritage as a historical and cultural value came relatively late, resulting in a large number of industrial abandonments, including transport infrastructure that became dysfunctional with changing industry and technology. Abandoned railway lines, in particular, are often located in areas where coal mining or heavy industrial activities have ceased, leading to the dysfunctionalisation of the sites. Moreover, the gradual modernisation of railway systems resulted in the decommissioning of many historic lines of high engineering and architectural value (Merciu et al., 2022).

In the 1970s, in response to concerns about the potential environmental threats posed by the demolition of industrial buildings, meetings began to be organised under the leadership of various universities and conservation organisations. These reactions, which were initially shaped by environmental concerns, gained a different dimension in time with the effect of the sense of belonging of the workers who had worked in these buildings for many years. These developments paved the way for an increase in interdisciplinary studies on industrial areas and the emergence of concepts such as ‘industrial archaeology’, ‘industrial culture’ and ‘industrial area’. Thus, since the late 1970s, awareness for the conservation of industrial buildings has developed and these buildings started to be defined as a cultural value under the title of ‘industrial heritage’ in the second half of the 20th century. Since the mid-1980s, this conservation approach has expanded beyond the structural scale to include large-scale industrial areas (Gür, 2019).

In 1977, the exhibition ‘Off the Rails’, organised as part of the ‘SAVE Britain's Heritage’ initiative, contributed significantly to raising awareness of railway heritage in the UK. After this exhibition, the preservation of railway buildings with historical and architectural value came to the agenda; Manchester Central Station was re-functionalised instead of being demolished in 1980 and became one of the first applications that set an example for this process. By 1997, a total of 60 railway lines were under protection in the country, and by 2003, more than 2,000 railway structures were officially protected. Today, although railway heritage is generally evaluated within the framework of industrial heritage and industrial archaeology disciplines, historical railway lines and structures are specifically addressed under the title of ‘railway heritage’ within this inclusive framework (Kösebay Erkan & Ahunbay, 2008).

Railway heritage is not only an element reflecting the function of transport infrastructure in the past, but also a multi-layered cultural value bearing the traces of social, technological and spatial transformations. Railway structures, which played a central role in shaping the processes of urbanisation, mobility and economic development after the industrial revolution, constitute important reference points in terms of historical memory with their engineering achievements, architectural styles and urban locations. The preservation of this heritage is critical both for the reuse of environmental and economic resources in line with sustainable development goals and for ensuring cultural continuity. In addition, the re-evaluation of abandoned or defunct railway buildings is of great importance in terms of integration with modern transport systems, preservation of urban identity and urban aesthetics.

3.3. Evaluation of railway heritage from sustainable development perspective

The term sustainable development was first defined in the ‘Our Common Future’ report prepared by the United Nations' World Commission on Environment and Development (WCED) chaired by Gro Harlem Brundtland. In this report, sustainable development was defined as a development that meets the needs of the present without jeopardising the ability of future generations to meet their own needs (Basiago, 1999; Redcliff, 2005 as cited in Gedik, 2020). The Venice Charter, adapted and published by ICOMOS in 1965, emphasises that the protection of cultural heritage sites is a responsibility towards future generations (ICOMOS, 2023).In the early 1960s, the interaction between sustainability and conservation was emphasised by conservation experts and this relationship has been widely covered in the international conservation literature over time.In the following years, the Paris Declaration published by ICOMOS in 2011 stated that development-oriented investments and practices can lead to negative consequences that threaten heritage sites and their values. Therefore, it was stated that heritage sites, as fragile and non-renewable resources, should be protected for the benefit of future generations (ICOMOS, 2011). In this context, the expressions ‘future generations’ and ‘non-renewable resource’ clearly reveal the strong relationship of cultural heritage with the concept of sustainability.

With the development of conservation theory and sustainable development studies over time, the importance given to sustainability in heritage conservation policies has gradually increased. Following the 2030 Agenda adopted by the United Nations in 2015, the International Council on Monuments and Sites (ICOMOS) established the Sustainable Development Goals Working Group (SDGWG) to develop strategies related to sustainable development goals (ICOMOS, 2016). In the report published by this group, the role of tangible and intangible, natural and cultural heritage elements in achieving the Sustainable Development Goals is clearly emphasised. According to the report, integrating cultural heritage into various dimensions of sustainable development offers multifaceted contributions such as increasing social resilience, strengthening a sense of identity and belonging, and supporting environmental sensitivity (ICOMOS SDGWG, 2021).

This study aims to evaluate the process of integration of historical railway stations with high speed train systems from the perspective of the 17 Sustainable Development Goals (SDGs) announced by the United Nations in 2015. The SDGs that directly overlap with the scope of the study and the relationships established with them are explained below:

3.3.1. SDG 9 - Industry, innovation and infrastructure

This goal aims to develop sustainable infrastructure systems, promote inclusive and sustainable industrialisation and disseminate innovative practices. Within the scope of the study, the process of integrating historical stations into the existing railway infrastructure, transforming these structures in accordance with technological requirements and integrating them into high-speed train systems overlaps with the principles of ‘resilient infrastructure’ and ‘innovation-based transformation’ of the target. In this way, while cultural continuity is ensured by integrating historical buildings into modern transport networks without demolishing them, the functional efficiency of infrastructures is increased.

3.3.2. SDG 11 - Sustainable cities and communities

This goal aims to make cities inclusive, safe, resilient and sustainable. The preservation and re-functioning of historic railway stations contributes to strengthening cultural identity by ensuring the continuity of urban memory and architectural heritage. In addition, making transport systems sustainable with railway-based solutions helps to reduce urban traffic load and emission rates. Thus, both the quality of social life is improved and spatial sustainability is supported.

3.3.3. SDG 12 - Responsible production and consumption

This target envisages efficient use of natural resources, reduction of waste production and promotion of sustainable consumption and production patterns. Repurposing and adaptive reuse of existing historic stations, rather than new construction, helps to reduce the environmental burden of development. This approach not only reduces carbon emissions from construction activities but also minimises material and energy consumption.

3.3.4. SDG 13 - Climate action

This target aims to take urgent measures to combat climate change. Railway systems, especially high speed train lines, have a lower environmental impact in terms of carbon emissions compared to road and air transport. Therefore, prioritising railways in transport and integrating historical infrastructures into this system is important for reducing the carbon footprint. Moreover, such practices encouraging public transport are in line with long-term climate strategies.

3.3.5. SDG 8 - Decent work and economic growth

This goal includes elements such as increasing employment, supporting economic growth and ensuring inclusion in the labour market. The renovation of railway stations and their integration into modern transport projects creates new employment opportunities for various occupational groups in the planning, restoration, construction and operation processes. In addition, revitalised activities in these areas strengthen local economic dynamics and create new opportunities for the service sector and small businesses.

3.3.6. SDG 15 - Life on land

This goal aims to protect terrestrial ecosystems, sustain biodiversity and prevent the destruction of natural areas. The re-functioning of historic railway infrastructures means using existing areas without creating construction pressure on new areas. Indirectly, the reduced need to intervene in nature due to new development contributes to the protection of natural habitats.

3.4. Approaches to the integration and adaptive reuse of historical station buildings with high speed railway systems

This section explores how historic railway station buildings are integrated and adapted for use within high-speed railway systems. The goal is to balance heritage preservation with the demands of modern transportation. Using examples from different countries and cities, the section looks at architectural design, new uses, and planning strategies. It also assesses how these approaches support sustainable urban development, protect cultural heritage, and improve transport system integration.

3.4.1.Oslo central station & Nordic light (Norway)

Oslo Central Station, opened in 1854, originally served Norway's first railway line, the Christiania–Eidsvoll route. Over time, the station expanded and became one of the most important transportation hubs in Norway throughout the 20th century. Under the "Nordic Light" project, the station underwent a transformation that combines Scandinavian minimalism with environmental sustainability principles. The use of natural and recyclable materials such as wood, glass, and stone is notable, alongside open public spaces and interior arrangements designed to maximize natural light. Energy-efficient systems and green design strategies have endowed the station with new functionality. As a historical structure, Oslo Central Station has been reimagined with modern architecture, integrating sustainable materials, energy-saving systems, and public spaces under the Nordic Light project. Both functionality and environmental sustainability were given high priority in this redevelopment.

Fig. 1. Oslo Central Station & Nordic Light (Reiulf Ramstad Arkitekter, 2025)

3.4.2. Atocha station (Madrid, Spain)

Cultural continuity has been ensured through both the preservation of the historic terminal and the construction of a new terminal building serving high-speed rail lines. The botanical garden and interior spaces within the station reinforce the theme of sustainability. Atocha Station was built in 1851 and has since become Madrid's largest and busiest railway station. The monumental iron-and-glass entrance hall, designed in 1892 by Alberto de Palacio, is particularly notable. In 1992, with the integration of the high-speed rail system, the station was expanded, and the interior of the original building was transformed into a botanical garden. This intervention preserved the historic structure while creating a public space that enhances spatial sustainability. The new terminal building, designed by Rafael Moneo, establishes a balance between contemporary architectural lines and historical architecture.

Fig. 2. Atocha station (Freepik, 2023; The Wandering Passport, 2024)

3.4.3.Vilnius Railway Station (Lithuania,Vilnius)

Built in the late 19th century, Vilnius Station is one of the key hubs in Lithuania's railway history. Redesigned within the framework of the European Union's Green Deal principles, the station has been supported by open spaces oriented toward the city center and transportation routes prioritizing pedestrians and cyclists. The new design embraces a nature-integrated transport architecture that emphasizes green infrastructure. In this way, the station has been reimagined to establish a stronger connection with the urban fabric while also being integrated with sustainable infrastructure.

Fig. 3. Vilnius Railway Station(Godfrey, 2025)

3.4.4. California high-speed rail (USA, California)

This system, currently under construction, constitutes the first full-scale high-speed rail line in the United States. As part of the project, several historic train stations have been preserved and integrated with modern high-speed rail terminals. This approach establishes a hybrid station model that maintains local identity while addressing contemporary transportation demands.

Fig. 4. California High Speed Railway Station(The High Speed Rail Alliance, 2024)

3.4.5. Ankara railway station / Ankara high-speed railway station (Türkiye, Ankara)

Completed in 1937, Ankara Railway Station is a significant transportation structure reflecting the modernist architectural approach of its time and is considered a spatial representation of the Republican ideology. With its simple geometric masses, symmetrical layout, and monumental entrance axis—characteristic of Early Republican architecture—it has reinforced its symbolic position in the history of rail transport in Türkiye.

The Ankara High-Speed Rail (HSR) Station, which became operational in 2016, was positioned adjacent to the historic station complex to meet the increasing passenger demand and to accommodate the integration of high-speed rail lines. However, the new structure has been heavily criticized for its architectural language, façade character, and impact on the urban silhouette, particularly in terms of the relationship it establishes with the existing historical context. In line with conventional conservation principles, newly built structures in historic settings are expected to be sensitive to their surroundings, and to align in scale and materials; yet, Ankara HSR Station is argued to exhibit only limited compliance with these standards.

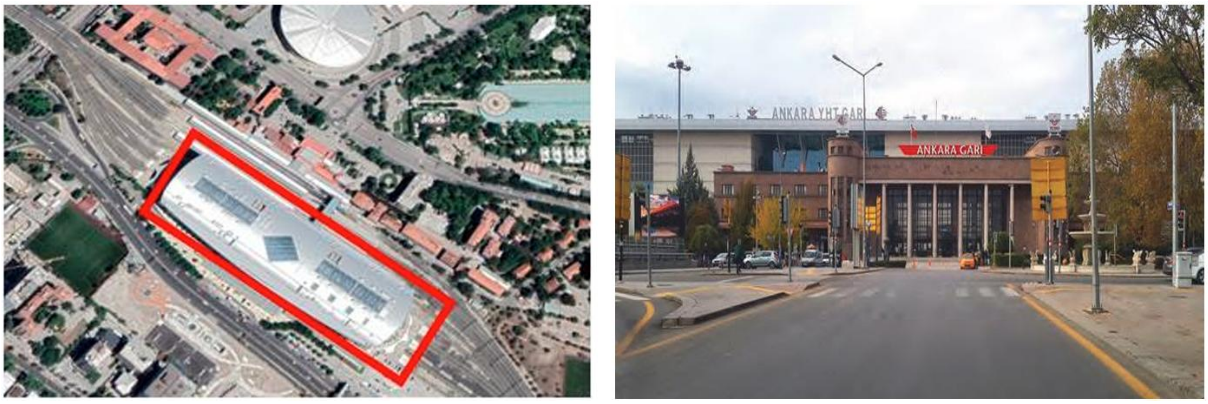

Fig. 5. Ankara high speed railway station (Altın, 2025)

3.4.6. Konya railway station / Selçuklu high-speed railway station (Türkiye,Konya)

Konya's historic railway station has served as a transportation hub since the Ottoman era. The new Seljuk High-Speed Train (HSR) Station was constructed at a separate location from the historic station. While this separation has been criticized in terms of physical and cultural continuity, it has enabled the efficient operation of high-speed rail services.

Fig. 6. Selçuk high speed railway station (Konya Büyükşehir Belediyesi, 2023)

3.4.7. Eskişehir railway station/ Eskişehir high-speed railway station project (Türkiye, Eskişehir)

Eskişehir holds a significant place in Turkey's railway history, spanning from the Ottoman Empire to the Republic. The city has made a significant contribution to the railway industry through its production and maintenance activities, a legacy that has been preserved to the present day. In accordance with this historical background, the Eskişehir High Speed Train Station (HSR) was designed by the renowned architects Orhan Uludağ and Prof. Dr. Zeynep Uludağ and completed in 2014. The newly constructed station building, which has been integrated into the city centre, aims to ensure the integrity of transport and urban structure. The edifice has garnered acclaim for its architectural conception, having been the recipient of the National Steel Structure Award in 2018 and the World Architecture Award from the World Architecture Community in 2020 (UMM, 2021). Nevertheless, concerns have been raised regarding the necessity to enhance the connection between the edifice and the historical station building, as well as the social memory of the city. This situation demonstrates that cultural heritage should be protected not only in physical but also in social aspects

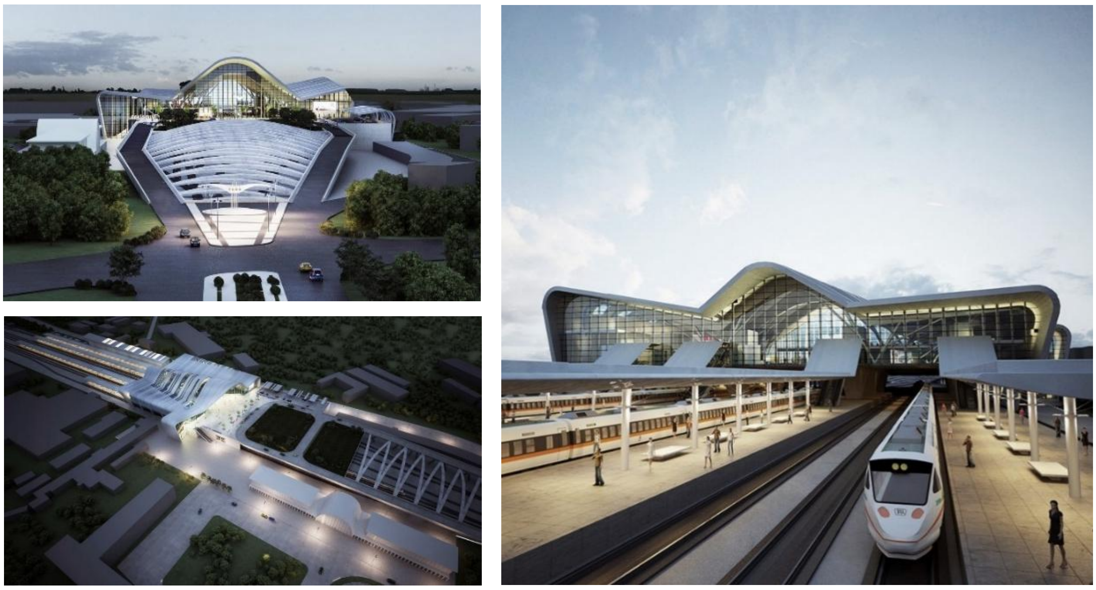

Fig. 7. Eskişehir high speed railway station (Arkitera Mimarlık Merkezi, 2025)

3.4.8. Adana railway station / Adana high-speed railway station project (Türkiye,Adana)

Opened in 1912, Adana Station has been one of the region's key transportation hubs during both the Ottoman and Republican periods. As part of the HSR project, efforts are being made to preserve the historic station and integrate it with the new infrastructure systems. Within the scope of the Adana HSR Station Project, adaptive re-use of the 1916-built historic warehouse building was proposed by the contractor. The original floor plan and façade design of the building have been preserved to ensure its integration with the new structure. The old warehouse building is intended to be refunctining as a restaurant. At the same time, the new HSR Station building has been designed with an architectural approach that respects the historical identity of Adana Station and its visibility within the city. The project's main principles include creating a balanced architectural transformation, taking into account the station's strategic location and historical significance.

Fig. 8. Adana High Speed Railway Station (Çizgi Hisar Mimarlık,2020)

4. Conclusions

This study examines the role of railway transport in the context of the Sustainable Development Goals (SDGs), with a particular focus on the integration and adaptive reuse of historic station buildings in high-speed rail systems. It highlights that historic buildings should not only be considered as aesthetic or nostalgic elements, but also as strategic assets that can contribute to sustainable urban development, environmental responsibility and economic resilience.

The SDGs approach heritage conservation not only as a matter of conservation, but also as a multidimensional development tool linked to social inclusion, economic vitality and environmental balance. In this context, the adaptive reuse of historic railway stations plays a crucial role in preserving urban identity and providing public spaces, in line with efforts to make cities more inclusive and sustainable. Furthermore, the reuse of existing structures reduces material consumption and construction waste, supporting resource efficiency and circular economy principles.

As a low-emission mode of transport, rail systems make a significant contribution to climate change objectives. By revitalising historic stations rather than demolishing and rebuilding them, the environmental impact is minimised. Integrating historic infrastructure with modern technology not only preserves architectural heritage, but also modernises transport networks in line with innovation and resilient infrastructure goals. In addition, such projects support local employment and stimulate economic activity through newly created functions and services, especially in sectors such as tourism and cultural industries.

Moreover, the reuse of existing buildings serves to reduce pressure on land development, thereby contributing to the protection of natural areas and terrestrial ecosystems. In essence, the adaptive reuse of historic station buildings signifies a comprehensive strategy that transcends mere physical transformation, embodying a holistic approach that seamlessly integrates the imperatives of cultural heritage conservation, urban sustainability, and integrated development.

By repositioning cultural heritage as both a driver and accelerator of sustainable development, the SDGs serve to dissolve the long-standing dichotomy between conservation and progress. Consequently, the integration of historic railway architecture into contemporary high-speed transport systems represents a strategic step towards the creation of more liveable cities and the safeguarding of cultural identity for future generations.

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Damage observations of February 6th 2023 Earthquakes on historical buildings in Kahramanmaraş

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Abstract. The purpose of the study is presenting observations about the damages of some historical buildings because of the February 6th 2023 Earthquakes, which affected eleven cities including Kahramanmaraş. This study presents the observations about the damages of some historical buildings in Kahramanmaraş, carried out immediately after the earthquakes. In the study, the pre-earthquake conditions of damaged historical buildings were investigated and transformed into base data through literature reviews. Then, the post-earthquake conditions were determined by site observation carried out in the city. There are severely damaged cultural assets in Kahramanmaraş. The damage pattern of the monuments gives insight for the weaknesses of the structures. This study contains research, observation and preliminary results about the damages of some of the historical monuments in Kahramanmaraş after earthquakes. The documentation of many damaged historic buildings in the earthquake zone is quite crucial in respect to the evaluation of damage reasons and further repairs.

Keywords: Cultural heritage; Damage assessment; Earthquake; Historical monuments; Kahramanmaraş

1. Introduction

The February 6, 2023 earthquakes affected a huge area and caused severe damage in eleven cities. Kahramanmaraş was one of the most severely damaged cities in the region due to its epicenter. On the morning of February 6, the first earthquake in Pazarcık was followed by a second earthquake in Elbistan, further increasing the damage in the city.

Although Kahramanmaraş, which was established on a fault line in Anatolia, has experienced many earthquakes in its history, some of them caused the city to collapse completely (Gümüşalan, 2012, p.226). The earthquakes with the highest destructive power occurred in the 12th and 18th centuries and caused many casualties. In the earthquake on November 29, 1114, more than 40,000 people lost their lives, and then the cold intensified contrary to seasonal norms and the loss of life reached around 100,000 due to the effect of weather conditions when snow fell after the earthquake (Kesik, 2001, p.32). Mateos of Urfa, one of the most important historians of the period, stated that no one survived in this earthquake (Andreasyan, 1987, p.255).

Sources indicate that there were other earthquakes of mild intensity in Kahramanmaras region in the same century, but another earthquake of similar intensity occurred in 1114 and another in 1115 (Gökhan, 2008, p.150). The epicenter of this earthquake was the ancient city of Misis, 27 km from Adana, and it is known that Misis and Kahramanmaras were completely destroyed, while Antakya was severely damaged (Fulcher of Chartes, 1969, p.214). Mihail the Syriac, one of the most important historians of the period, described the severity of this earthquake as blowing up the foundations of Kahramanmaras and causing pieces of the buildings to fall to the ground (Syriac, 1924, p.60-61). In addition, many historians of the period such as Ibn al-Asir, Ibn al Kalanisi, Ibn al Adim, Simbat, Aynî recorded the 1115 earthquake and stated that the epicenter was in Syria, although they did not directly state that the earthquake was in Misis (Gökhan, 2008, p.150). Considering the locations of the historians during this earthquake, the size of the earthquake zone can be estimated.

In Kahramanmaraş and its surroundings, where many communities had settled, such as the Hittite Empire was established in the same lands (Gümüşalan, 2012, p.4). During the Assyrian period, Kahramanmaraş became an important trade route through which caravan routes crossed Mesopotamia, Northern Syria and Central Anatolia, thus making the region strategically important (Gümüşalan, 2012, p.6). This city, which was wanted to be included within its borders by many communities, was under the sovereignty of the Hittites, Assyrians, Medes, Persians, Macedonians and the Great Roman Empire respectively (Gökhan, 2008, p.21). Kahramanmaraş is known as

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"Maraj" or 'Markasi' in Hittite sources and "Germenika" in Roman sources (Gümüşalan, 2012, p.4). After the conquest of muslims, the city kept its importance during Seljuks, Ottomans as well as until today.

2. Methodology

This study focuses on monumental cultural heritage structures classified within the first-degree protection category. Alongside on-site assessments, qualitative and quantitative data were gathered from a wide range of sources, including testimonies and reports from central and local authorities, public officials, institutions, media outlets (both national and local), and non-governmental organizations. To efficiently organize and interpret the information collected from multiple channels, a comprehensive database was developed.

Orthophotos obtained from the HGM Atlas—an application developed by the General Directorate of Mapping—were utilized during the evaluation process to determine the locations and conditions of damaged structures. All collected data were integrated into a cloud-compatible web-based Geographic Information System (GIS) platform, where they were visualized on a digital map. Upon completion of the data input phase, several distinct data sets were generated as output. Although the study area covers all 11 districts of Kahramanmaraş, this study focused on the Dulkadiroglu region, which is the center of the city, as it is more accessible than the other districts and has many buildings with damage. Observational damage assessments were made for the buildings in this district, which houses most of the cultural assets in the city.

Given the extensive geographic scope and the widespread distribution of cultural heritage assets across rural areas in the 11 provinces impacted by the earthquake, conducting a comprehensive damage assessment necessitates a large-scale organizational effort and a considerable investment of time. Accordingly, this study was limited to a selected sample area to enable focused and systematic analysis. Kahramanmaraş is one of the provinces that suffered heavy damage due to its epicenter. In light of the extensive scale of the disaster area and the prevailing challenges related to infrastructure and accessibility, the number of sites addressed in this study already represents a substantial fieldwork effort. Consequently, the scope was narrowed to focus specifically on principal cultural heritage structures within Kahramanmaraş. Nonetheless, due to access limitations, it was not possible to reach all targeted buildings; therefore, the findings presented should be regarded as partial and subject to the constraints of the available data (Dabanli et al., 2023).

3. Findings

3.1. Foundational cultural assets in Kahramanmaraş and damages

Dating back four thousand years, Kahramanmaraş and its surroundings are one of the oldest settlements in the Mesopotamia region and are known to have hosted many civilizations. The layers identified as a result of archaeological studies in this region date from the Ottoman Period to the Neolithic Age (Gökhan, 2008, p.42). As a remarkable case, it was determined that the region was an important settlement during the Persian, Hellenistic Roman and Byzantine periods according to the findings obtained from the studies carried out in Pazarcık in 1958 and 1969 (Kılıç, 1961, p.40).

There are 45 foundation works in Kahramanmaraş, including 27 mosques, 1 mosque-madrasa, 1 mosque-tomb, 1 inn, 1 caravanserai, 1 masjid, 9 minarets, 1 ribat, 2 tombs and 1 cemetery (Foundations Journal, 2023, p.22). While the majority of these works belong to the Dulkadir Principality period and preserved their authenticity for many years, disasters such as earthquakes and fires in the 19th century and the chaotic environment of the First World War caused many buildings to be damaged (Gümüşalan, 2012, p.281).

Dulkadiroğulları developed a unique architectural style by synthesizing the stonework of Aleppo and Damascus with Mamluk influence. Within the scope of this study, it was determined that 44 of these foundation buildings were severely damaged in the February 6 earthquakes. These damaged buildings are located 17 in Dulkadiroğlu, 7 in Onikişubat, 7 in Afşin, 7 in Elbistan, 2 in center, 2 in Pazarcık, 2 in Çağlayancerit. Although Kahramanmaraş consists of 11 districts, the damaged buildings that are old monuments are located in 7 districts.

3.1.1. Grand Mosque of Kahramanmaraş

Kahramanmaraş Grand Mosque was built between 1442-1454 during the Dulkadiroğlu Principality period and became the center of the city during the Dulkadiroğlu period with the construction around it and maintained its importance during the Ottoman period (Çetin, 2018, p.17). The mosque, as the largest mosque of the city in the 16th century (Gökhan, 2019, p.394), is also known as Cami-i Kebir, Cami-i Âtik, Alâuddevle Bey Mosque and Süleyman Bey Mosque (Çobanoğlu, 2012, p.111). This building, where many declarations were announced to the public during the National Struggle Period, has a special importance in terms of the history of the city as it is the place where sermons were given for the liberation struggle during Friday prayers (Çetin, 2018, p.13).

It is learned from the inscription on the main gate of the mosque that it was repaired in 1501-1502, 1780, 1853-1854, 1897 and 1945, and it is known that the repair in 1780 was due to fire (Çobanoğlu, 2012, p.111). In 1848, the minaret of the mosque was built by Hacı Halil Bey from the Zülkadir family, one of the elite families of Maraş, and the minbar of the mosque was built by Mehmet Esad Bey from the same family in 1899-1900, but these repair activities are not included in the inscription of the building (Gökhan, 2019, p.409; Alpaslan et al., 2008, p.55). In addition to the building in question, various demolitions were also realized. An example of this situation is the demolition of the muvakkithane, which was built as a period addition in 1945 (Çobanoğlu, 2012, p.111).

In 1960, the Italian city planner Puccinati was commissioned to draw up a new zoning plan for Maraş, which included the restoration of the Grand Mosque, Isa Divanlı Mosque and Elbistan Grand Mosque (Gökhan, 2019, p.796). Although the Grand Mosque was restored in 1945, the decision to restore the building again in 1960 is a separate issue that needs to be studied. Located in the Dulkadiroğlu region of Maraş, the mosque was damaged in the February 6 earthquakes. Some parts of the stones near the keystones of the arches inside the mosque fell on the floor of the building and the minaret of the mosque collapsed, while the minaret stones fell on the portico and caused damage to the roof of the building in various dimensions (Fig. 1.). Luckily the minaret did not collapse totally, remaining approximately half of it in its original state. But according to the recent information, the remaining part of the minaret was demolished and there is no trace of the minaret today.

Fig. 1. Grand Mosque, before (M.Cambaz) and after (F.Al) earthquake

3.1.2. Çukuroba Mosque

Çukuroba Mosque, also known as Hacı Hüseyin Efendi Mosque, located in the city center, was built in 1640. During the War of Independence, it was heavily damaged as a result of being bombed by Armenians and only its minaret survived (Başkan, 2006, p.90; Özkarcı, 2007, p.11; Çetin, 2018, p.15). In the same period, almost half of Maraş burned down as a result of a large fire that spread rapidly in the city, and while some neighborhoods were completely destroyed, a few neighborhoods such as Çukuroba were heavily damaged (Çetin, 2018, p.18). In the first half of the 20th century, Çukuroba Mosque, which was heavily damaged twice, was reconstructed in 1940 (Özkarcı, 2007, p.11).

Built in the 17th century, the inscription of the Çukuroba Mosque states that its minaret was built in 1720. In addition, there is a two-storey dergah (sufi lodge) building in the courtyard of the mosque, and it is learned from the inscription that it was built in 1897 as an annex. During the February 6 earthquakes, the minaret of the mosque was destroyed up to its pedestal, while the minaret stones fell on the courtyard walls, causing part of the wall to collapse (Fig. 2).

Fig. 2. Damage to the minaret of Çukuroba Mosque, before (Z.Aytemiz) and after (F.Al) earthquake

3.1.3. Sheikh Mosque

The construction date of the mosque, also popularly known as Şıh Mosque, Şeyh Müslim, Şeyh Hüseyin or Şeyh Turan Mosque, is not known for certain since its foundation and inscription have not survived to the present day, but architectural influences of the 16th century are observed in accordance with the general Dulkadiroğlu region (Özkan et al., 2024, p.79). The Sheikh Mosque (Başkan, 2006, p.86), which is estimated to have suffered a fire in the 1930s, was built on the same level as the original harim level, and it is estimated that the door and arch details belong to the original structure (Özkan et al., 2024, p.88). The dome of the building was brick, the body walls were stone masonry, and the roof of the portico, which originally had wooden beams, was covered with concrete in a repair work (Özkarcı, 2012, p.110).

One of the buildings in Kahramanmaraş that was completely destroyed in the February 6 earthquake is the Sheikh Mosque. Since the roofing system, body walls and minaret of the mosque were completely destroyed, the boundaries of the Sheikh Mosque were determined from the lead dome coverings and the realm. Interestingly, no vertical structural elements were found standing in the ruins of the mosque (Fig. 3).

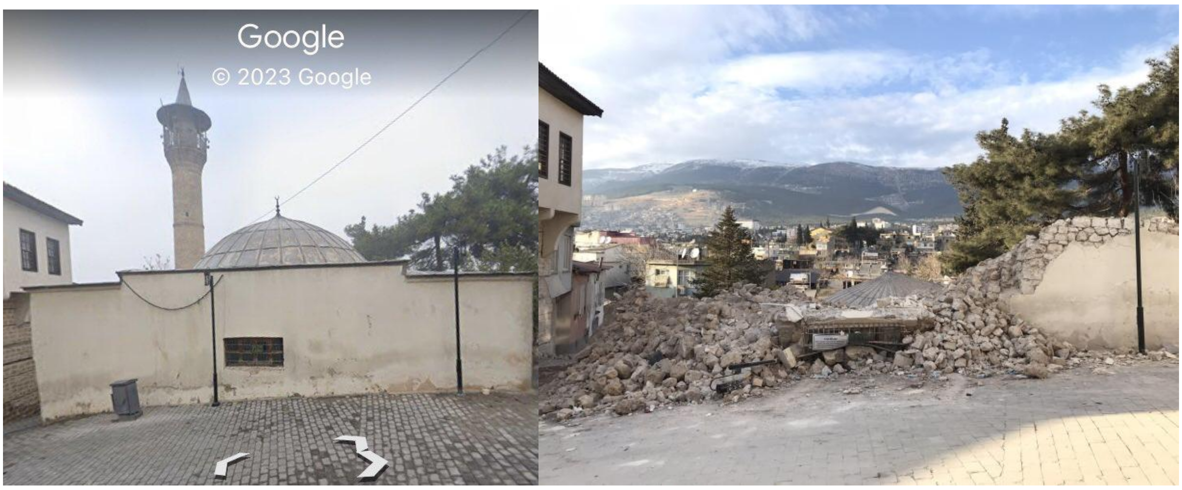

Fig. 3. Damage of the Sheikh Mosque, before (Google) and after (F.Al) earthquake

3.1.4. Şekerli Mosque

Şekerli Mosque, one of the original examples of local architecture, was built between 1695-1696. In this building, also known as Yukarı Oba Mosque or Ahmet Paşa Mosque, stone masonry was preferred for the body walls in accordance with the structural material preference of the region, while brick was used in the roofing system (Özkarcı, 2012, p.117). Settled on sloping terrain, the portico and the minaret, half of which is flat and half twisted, are the unique elements that distinguish the Şekerli Mosque from other works. Repaired in 1856, the mosque was rebuilt in 1888 and repaired again in 1937 (Özbey, 2020, p.214). The mosque also had a madrasah that has not survived (Özkarcı, 2012, p.117). On February 6, Şekerli Mosque was severely destroyed, and only the wall with the main gate and the portico survived, but the arches of the portico were heavily damaged (Fig. 4.).

Fig. 4. Şekerli Mosque, before (Google) and after (F.Al) earthquake

4. Conclusion

Throughout history, wars, epidemics and disasters have been the main cause of mass casualties. Since the 12th century, Kahramanmaraş has been a region where disasters and wars have been experienced many times, sometimes the city was completely destroyed by earthquakes, while others were deliberately destroyed in wars. Cultural heritage plays a key role in the continuity of urban memory, even after multiple destructions.

Although Kahramanmaraş, which has been shaped around the Grand Mosque and its surroundings since the Dulkadiroğlu period, has destroyed many times, the city center has not changed. This situation, which shows the impact of cultural assets on urban memory, is an important reference point for restoration and conservation works.

In the February 6 earthquakes, some of the historical buildings in Maraş were destroyed. While some of the hundreds of years old buildings were severely damaged, others were completely destroyed. Preserving the original characteristics of the cultural heritage, which is one of the main principles of restoration, is an issue that needs to be studied for buildings in the earthquake zone and restoration and reconstruction works should be designed by considering the weak points of the original structural system. The destruction of almost all historical buildings in the February 6 earthquakes highlights the vulnerability of cultural assets in the region.

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Conservation issues in mixed heritage sites: The cases of Akdamar Island, church and side

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Abstract. Turkey is a geography distinguished by its rich cultural heritage and mixed heritage sites that encompass overlapping designations such as historical-archaeological, urban-natural, and urban-archaeological-natural. While legislation and principles for the protection of heritage sites have been developed, the challenges arising in areas where multiple site statuses intersect remain inadequately addressed within national regulations. These challenges often involve ambiguities in authority-responsibility allocation, conservation, and usage conditions, as well as prioritization dilemmas regarding which value should be emphasized in interventions.
This study examines the current issues related to the protection of mixed heritage sites, focusing on the examples of Akdamar Island and Church (archaeological and natural values) in Van and Side Ancient City (urban and archaeological values). Through literature review and field studies, the conservation problems experienced in these areas are analyzed.

The findings underscore the importance of accurately defining and classifying mixed heritage sites. Such an approach can clarify authority-responsibility sharing and foster the development of integrated strategies for protection, leading to a more effective and comprehensive conservation process.

Keywords: Mixed Heritage; Cultural Heritage; Akdamar Island; Side Ancient City; Conservation Strategies

1. Introduction

The Cultural heritage sites, which carry the traces of the past into the present, are of great importance for societies to understand and preserve their historical and cultural identities. Among these areas, conservation sites (sit areas) stand out as regions that require special protection due to their unique values and holistic structures. The preservation of conservation sites requires an understanding that encompasses not only individual structures but also the natural, historical, and urban environment in which these structures are located.

Internationally, the first regulations for the protection of heritage sites began with the Athens Charter in 1931, followed by a more comprehensive approach to the concept of conservation introduced by the Venice Charter published in 1964 (Ahunbay, 2017, pp. 8-20). Especially the Venice Charter, by adopting a conservation approach ranging from the scale of individual buildings to the scale of the environment, formed the basis for the national legislations of many countries. In 1975, the Amsterdam Declaration introduced the concept of "integrated conservation" and emphasized the sustainability of historical and cultural values. The necessity of protecting not only urban areas but also rural areas was addressed (Jokilehto, 1999), (Perrault , 1993) ,(Viollet-le-Duc, 1990).

In Turkey, the official conservation process began with the *Âsâr-ı Atîka Regulation* of 1869, and modern conservation approaches were adopted with the Antiquities Law enacted in 1973. This law enabled the definition of concepts such as "historical site," "archaeological site," and "natural site," and with the enactment of Law No. 2863 on the Conservation of Cultural and Natural Properties in 1983, a more comprehensive understanding of conservation was developed. However, these legal regulations remain inadequate in providing clear definitions and strategies for mixed site areas where different types of sites converge (KTVKK, 1983), Âsâr-ı Atîka Nizâmnâmeleri (1869, 1874, 1884, 1906).

Mixed site areas, especially in regions where natural, archaeological, historical, and urban values geographically overlap, bring about numerous issues such as the sharing of authority and responsibility, conservation priorities, and conditions of use. In Turkey, the transfer of authority over natural site areas from the Ministry of Culture and Tourism to the Ministry of Environment and Urbanization has further complicated the management of mixed site areas. The ambiguities in defining overlapping areas make it difficult to adopt a holistic approach in conservation practices.

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In this study, the current issues related to the conservation of mixed site areas are addressed, and the conservation problems encountered in these areas are examined through the examples of Akdamar Island and Church in Van and the Ancient City of Side. Based on data obtained through literature review and field studies, the necessity of accurately defining and classifying mixed site areas for a more qualified conservation process is emphasized.

2. Site Statuses And Conservation Approaches In Turkey

In the processes of protecting cultural and natural assets, two different concepts emerge: conservation at the individual scale and conservation of values that form a whole and create a texture at the area scale. Concepts related to area-scale conservation include various types of conservation sites and archaeological sites. In the Convention Concerning the Protection of the World Cultural and Natural Heritage, the protection of cultural and natural assets is addressed under three main headings: individual scale, group protection of structures, and area-scale conservation.

In Turkey, the individual-scale conservation approach is implemented through the registration of cultural and natural assets and the independent protection of the registered assets. In area-scale conservation approaches, it is aimed to protect immovable cultural and natural assets within a designated area as a whole (Çolak N. İ., 2015, p. 164). For regions where area-scale conservation is decided, the site is declared as a conservation area, resulting in a legal status change for the area to be protected. Before the declaration of the site, the assets and qualities within the area that are deemed worthy of protection are identified, and the conservation boundaries of the area are determined. Based on the evaluations, an appropriate type of conservation site is designated for the area, depending on the nature of the values present. The types and numbers of conservation sites in Turkey are summarized in the table.

Table 1. Types of Conservation Sites and Their Numbers in Türkiye, (Republic of Turkey Ministry of Culture and Tourism (T.C. Kültür ve Turizm Bakanlığı))

Conservation Sites Across Türkiye	
Type of Sıte	Number
Archaeological Site	25.353
Urban Conservation Site	365
Historical Site	242
Urban Archaeological Site	36
Mixed Site	132
Natural Site	2.572
Total	**28.700**

Depending on the values and priorities that conservation sites carry within themselves, different site statuses are defined as archaeological, urban, historical, urban archaeological, and natural conservation sites (Table 1). The definitions of these conservation sites, along with their conditions of conservation and use, are determined in laws, regulations, and principle decisions. However, although 132 conservation sites were designated as Mixed Conservation Sites by the Ministry of Culture and Tourism as of the end of 2023, there is no definition regarding mixed conservation sites in the current legislation; and no section was identified in principle decisions or regulations in which the term “mixed conservation site” is explicitly mentioned.

The concept of mixed conservation sites, which is not clearly defined in the legislation, is occasionally addressed in the literature by experts in the field. For example, Ahunbay (2017) uses the term “complex site” for mixed areas and defines them as “areas with at least two conservation site characteristics” (Ahunbay, 2017, p. 27). Similarly, Madran and Özgönül (2005) define areas that contain more than one type of conservation site as complex sites, emphasizing the coexistence of natural, archaeological, and urban values in such areas in Turkey (Madran & Özgönül, 2005, p. 18). Mixed Conservation Sites have been classified and quantified by the Ministry of Culture and Tourism based on their distinctive characteristics (Table 2).

Table 2. Mixed Conservation Sites Across Türkiye **(**(Republic of Turkey Ministry of Culture and Tourism)

Mixed Conservation Sites Across Türkiye	
Type of Mixed Site	**Number**
Archaeological and Urban Conservation Site	73
Archaeological and Historical Site	18
Archaeological, Historical, and Urban Site	7
Historical and Urban Conservation Site	34
Total	**132**

As can be seen from the table, the "site areas statistics by provinces" available on the official website of the Ministry of Culture and Tourism categorize Mixed Conservation Sites under four separate categories: Archaeological and Urban Conservation Site; Archaeological and Historical Site; Archaeological, Historical, and Urban Site; and Historical and Urban Conservation Site, including only cultural aspects. The coexistence of these areas with natural conservation sites is not addressed, and such areas have not been evaluated or quantified.

In the legislation, the spatial coexistence of natural and cultural conservation sites is defined as "overlapping areas" as follows: "…Areas where natural sites and immovable natural assets coexist and overlap with cultural sites (urban, archaeological, historical, urban-archaeological) and registered immovable cultural properties…" (Protocol, 2012) [1].

Although the spatial coexistence of cultural and natural conservation sites has not yet been defined as mixed sites in Turkey, UNESCO defines the coexistence of natural and cultural values as mixed sites for areas to be included in the World Heritage List and requires the preparation of conservation and management plans accordingly. In Turkey, only two sites have succeeded in being inscribed on the UNESCO World Heritage List as mixed properties: "Göreme National Park and the Rock Sites of Cappadocia (Nevşehir) 1985" and "Hierapolis-Pamukkale (Denizli) 1988."

In Turkey, the conditions for the conservation and use of mixed conservation sites are not clearly and explicitly defined in the legislation. The lack of appropriate legal regulations leads to various issues in the conservation of mixed sites and in the processes of authority sharing, management, use, and protection within these areas. This situation results in delays in planned activities, ineffective conservation, and the deterioration of the original values of the sites(Turkish National Commission for UNESCO).

In this study, the problems experienced in mixed conservation areas are addressed through concrete examples. The Akdamar Island in Van (archaeological and natural conservation site) and the Ancient City of Side in Antalya (urban and archaeological conservation site) were examined to identify the conservation issues encountered in these areas, and solution proposals were developed.

2.1. Van Akdamar Mixed Cultural and Natural Site

2.1.1. Akdamar Island: A Brief Historical Background

Akdamar Island, situated in the middle of Lake Van, represents a multilayered cultural heritage site distinguished by its natural landscape, the Akdamar Church a monument of significant importance to Armenian culture and the surrounding archaeological assets. Owing to these unique characteristics, the island was inscribed on the UNESCO Tentative World Heritage List in 2015 under the title "Akdamar Memorial Museum (Church)." Combining multiple cultural and natural values, Akdamar Island is recognized at both national and international levels as an important mixed site that requires preservation(Fig. 1).

Fig. 1. Van Akdamar Island

The Akdamar Church (Church of the Holy Cross) is located on Akdamar Island, within the boundaries of the Gevaş District in Van Province, situated in the Eastern Anatolia Region of Turkey, on Lake Van. As the largest lake in Turkey, Lake Van plays a significant role in shaping the natural and cultural identity of the region. Akdamar Island, historically referred to as Aghtamar, Akhtamar, or Ahtamar, is the second largest of the four islands located

[1] https://teftis.ktb.gov.tr/Eklenti/507 9,en-son-protokol-metni- 2982012.doc?0

within Lake Van. The island covers an area of approximately 700,000 m² and lies about three kilometers from the mainland (Van Akdamar Church).

The church was constructed between AD 915 and 921 under the supervision of Architect Bishop Manuel, commissioned by King Gagik I Artsruni, an Armenian monarch who ruled as a vassal to the Abbasid Caliphate during the period of the Kingdom of Vaspurakan. Akdamar Church reflects the flourishing cultural and artistic achievements of the Vaspurakan Armenian Kingdom during its peak period (Öney, 1989, pp. 1–2). The church fully embodies the cultural diversity and religious interactions characteristic of the Vaspurakan Kingdom in the 10th century, particularly through the dense relief decorations that adorn its façades. The richly ornamented exterior walls, featuring depictions of significant religious symbols and numerous historical events, contribute to the building's distinctive and authentic character (Öney, 1989, p. 11), (Fig. 2).

Fig. 2. The stone reliefs located on the eastern façade of the church (Ornamentation of Van Akdamar Church)

With the end of the Kingdom of Vaspurakan in the early 11th century, its territories were ceded to the Byzantine Empire. The structures on Akdamar Island were converted into a monastery in 1113 (Bachman, 1913). By 1882, a catholicos residence, a seminary, cells, a laundry area, a kitchen, and a cistern within the courtyard were added around the church courtyard (Fig. 3).

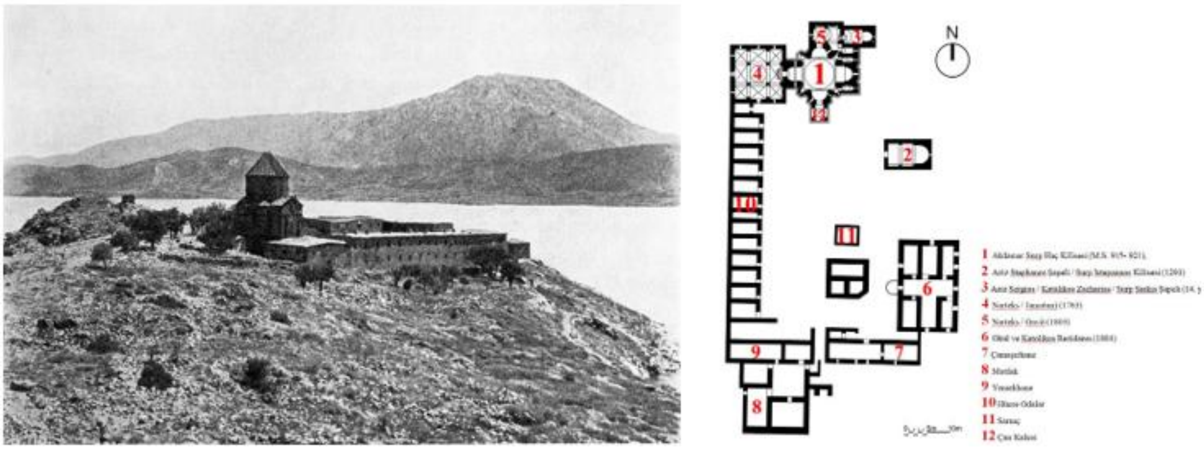

Fig. 3. According to Bachmann, the monastery plan

Until 1895, the Armenian Patriarch continued to serve alongside the structures surrounding the church. Due to political issues in the country between the 17th and 19th centuries, in 1918, the Armenian population living on the island was forced to migrate. After the island was abandoned, the site remained unused until 2005, leading to neglect and damage to the structures and their surroundings (Öztürk, 2019, p. 863). In 2003, the Ministry of Culture and Tourism initiated a restoration project to preserve the complex, with excavations starting in 2006. The site was opened to visitors as a memorial museum in 2007 (Öztürk, Biber, Çavuşoğlu, & Karaca, 2007, pp. 60, 61).
Beyond its cultural significance, Akdamar Island also holds remarkable natural value. The island is vital for species whose populations and habitats are diminishing. Its topography and vegetation provide a habitat for numerous bird species. The Akdamar Church and its surrounding natural environment form an inseparable, integrated whole.

Both natural and human-made values contribute to the island's identity and silhouette. Therefore, it is essential to approach the island as a unified site, preserving both its rich flora, fauna, and cultural heritage (Fig. 4).

Fig. 4. The Akdamar Church and Island, integrated with its nature (Akdamar church)

2.1.2. The Conservation Process of Van Akdamar Island

Akdamar Island became deserted due to the migration from the island in 1918 and remained unused for a long time. The structures, left empty for an extended period, became vulnerable to natural conditions, accelerating the deterioration process. By the 21st century, the issue of preserving the island and taking necessary steps toward it gained significant attention, and the first steps toward physically preserving the island were taken.

- In 1979, the High Council of Antiquities and Monuments declared the region an archaeological area, initiating the conservation process.
- In 1990, Akdamar Island was declared a first-degree archaeological site.
- In 2003, the Van Governorship and the Ministry of Culture and Tourism initiated survey, restitution, and restoration works to protect the cultural assets on the island (Öztürk, 2021, p. 235).
- In 2004, the projects prepared were reviewed and approved by the Diyarbakır Regional Directorate of the Protection of Cultural and Natural Heritage (Öztürk, 2019, p. 863).
- In 2005, the restoration process of the church and the chapels located on the east and northeast of the church began (Öztürk, Biber, Çavuşoğlu, & Karaca, 2007, p. 60).
- In 2006, excavation work began to uncover the complementary parts of the main structures located to the south of the church.
- The opening of Akdamar Church took place on July 31, 2006. In 2007, it began to accept visitors as a memorial museum. A religious service is held once a year at the church.
- In 2007, the Environmental Design Project was initiated to ensure access to the island, open the church for visitation, allow exploration of the building sections, and facilitate the connection with recreational areas (Öztürk, 2019, p. 871).
- The project includes ticket booths, pedestrian pathways, security rooms, indoor and outdoor seating areas, a cafeteria, souvenir shops, piers, observation terraces, disabled access, and beach arrangements (changing-dressing rooms).
- In 2010, the Eastern Anatolia Development Agency placed solar panels on the southwest of the island to meet the electricity needs of the structures on Akdamar Island (Öztürk, 2019, p. 871).
- A Landscape Design Project, covering Akdamar Island and all the structures on it, was prepared by the Ministry of Culture and Tourism. The project was reviewed and approved by the Van Regional Board for the Protection of Cultural Heritage with Decision No. 661 on July 15, 2010 (Van Regional Council for the Conservation of Cultural Heritage).
- In 2015, considering its values, Akdamar Church was included in the UNESCO Tentative World Heritage List.
- Considering the natural values of Akdamar Island, a large portion of the island was registered as a "Natural Site - Qualified Natural Conservation Area" with Decision No. 112213 on May 3, 2019 (Akdamar Island Natural Site Registration Announcement.).
- To ensure more sensitive protection of the natural values on the island, areas outside the previously designated qualified natural conservation areas were declared as "Strictly Protected Sensitive Area" in the Official Gazette No. 30822, published on July 4, 2019 (Fig. 5).

Fig. 5. Qualified Natural Conservation Area (left), Boundaries of the Natural and Archaeological Site (right), (Akdamar Island Natural Site Registration Announcement)

2.1.3. Problems Related to Preservation on the Island

Until 2011, the Ministry of Culture and Tourism was responsible for all site areas; however, following a regulation in the same year, authority and responsibility for natural site areas were transferred to the Ministry of Environment and Urban Planning. After this transfer, the publication of the "Regulation on the Procedures and Principles for the Determination, Registration, and Approval of Protected Areas" in 2012 led to significant changes in the classification of natural site areas. Areas previously classified as first, second, and third-degree natural sites were reclassified into three categories: Strictly Protected Sensitive Areas, Qualified Natural Conservation Areas, and Sustainable Protection and Controlled Use Areas.

- After the transfer of authority in 2011, coordination issues and power-sharing deficiencies became apparent in mixed site areas. Since Akdamar Island holds both natural and cultural values, these issues have been more pronounced. Inconsistent decisions due to overlapping authority hinder the protection and management processes.
- The island, which was previously registered as a first-degree natural and archaeological site, was re-evaluated in accordance with the regulation published in 2012 and registered as a Qualified Natural Conservation Area on May 3, 2019. The decision of January 5, 2017 (Decision No. 99) regarding Natural Site Protection and Use Conditions, which allowed the construction of bungalows and campsites in Qualified Natural Conservation Areas, was welcomed by the tourism sector. However, it raised concerns about the preservation of Akdamar Island's cultural and natural values. As a result, the regulation was amended on October 16, 2019, in the Official Gazette (Decision No. 30971), prohibiting the construction of bungalows in Qualified Natural Conservation Areas.
- The opening of Akdamar Island to visitors and the intensification of tourist activities have put significant pressure on the island's natural and cultural resources. Issues such as increased physical wear, environmental pollution, and degradation of the natural landscape make long-term preservation more difficult.
- Akdamar Island, with its natural and cultural heritage, is an important site. However, the insufficient steps taken for its preservation, along with the lack of regulations on the protection of mixed site areas in the legislation, result in the natural and cultural elements being evaluated separately, ignoring their interrelationship. This lack of a holistic approach to the protection of mixed sites has led to challenges in balancing the preservation of the island's natural and cultural elements.
- Akdamar Island faces significant challenges in the UNESCO nomination process. The inclusion of Akdamar Monument Museum (Church) in the UNESCO Tentative World Heritage List in 2015 is a crucial step, but it may lead to a perception that the island's natural values are less important than its cultural heritage. If the natural values are not adequately integrated with the cultural heritage, it could result in insufficient protection of the island's ecosystem and natural beauty. A focus on cultural heritage over natural values could undermine the development of sustainable protection strategies, emphasizing the need for a holistic approach to preserving Akdamar Island's diverse values.

2.2. Side Mixed Site Area

Located in the Manavgat district of Antalya, one of the important cities on Turkey's Mediterranean coast (80 meters to the east), Side is situated on a peninsula that is 400 meters wide. Due to its geography, location, climate, and fertile lands, it has attracted interest and been conquered by many civilizations. With its multi-layered historical texture, it is an important archaeological resource. In addition to its archaeological values, Side is one of the significant settlements that deserves preservation, as it combines both archaeological and urban values along with the unique cultural values of the Selimiye settlement. The Antalya Culture and Natural Heritage Conservation Board has designated this area as both an Urban and Archaeological Site.

Fig. 6. The ancient city of Side and the Selimiye settlement (Büyüksural, Karamağaralı, & Sağıroğlu Demirci, 2022)

2.2.1. An Outline of Side’s Historical Background

Side is one of the prominent coastal cities of ancient Pamphylia, a region located between Cilicia, Lycia, and Pisidia along the Mediterranean coast. Geographically, Pamphylia corresponds to the area between the Mediterranean Gulf and the Taurus Mountains in modern-day Antalya (Strabo, 2000, p. 249). The remains of columns, stones, and structures in Side indicate it was once a densely populated and prosperous city, largely due to its significant port and thriving trade network. The well-preserved ancient theater of Side, one of the finest examples surviving today, further reflects the city's importance (Corancez, 1816, pp. 375–378).

Side became a settlement in the 7th century BCE, came under Lydian rule in the 6th century BCE, and later passed to the Persians after Lydia’s fall. In 334 BCE, it opened its gates to Alexander the Great, becoming a center for coin minting during the Hellenistic period. After several shifts in power, Side was incorporated into the Pergamon Kingdom and later annexed by Rome following attacks by pirates in 78 BCE (Side Ancient City).

In the 20th century, Cretan immigrants founded the Selimiye settlement on the peninsula, merging with the ancient city. Today, Side preserves this integrated cultural landscape. The city features key elements typical of Pamphylian urbanism, including a monumental gate, colonnaded street, ancient theater, and harbor (Fig. 7, Side Ancient City)

Fig. 7. Side Ancient City

2.2.2. Conservation Process of the Ancient City of Side

Throughout its history, Side lost its significance as a major port city due to wars and external factors, leading to a long period of abandonment. During the reign of Sultan Abdulhamid II, Cretan immigrants were resettled in the area, establishing the Selimiye village between the ancient theater and the coast, which initiated the site's reoccupation (Soykal Alanyalı, 2016, p. 18). This multi-layered settlement, containing Hellenistic, Roman, Byzantine, and Ottoman cultural layers, introduced new challenges in terms of heritage conservation.

- Until the 1960s, no comprehensive conservation measures were implemented. The first planned efforts began in 1969 when the Ministry of Tourism initiated the "Side and Environs Tourism Planning International Competition," aiming to protect the archaeological remains while promoting tourism development (Çubuk, Güner & Gürsel, 1971, p. 30). The competition emphasized the conservation of major features such as the theater, harbor, and colonnaded street, while proposing controlled integration of new structures into the historic fabric.
- Following the competition, the 1/5000 scale Master Plan for Side and its surroundings was approved in 1971. Subsequently, in 1975, the Higher Council for Immovable Antiquities designated 98 civil architectural structures for protection, launching formal listing and planning processes (Boyacıoğlu, 2011, p. 8).
- From the 1970s to the 1990s, a series of plans and revisions were made to balance conservation with increasing pressures from tourism and local development. These included the designation of archaeological zones, restrictions on construction within the necropolis, and updates to conservation master plans, although implementation often faced resistance from local inhabitants and municipal authorities.
- Despite regulatory frameworks, unauthorized construction within the old village persisted. In 2012, in an attempt to better manage the area, part of the Köyiçi district was reclassified as an Urban and Third Degree Archaeological Site (Official Gazette, 2012). In 2019, after new evaluations, revisions were made to the boundaries of the protected zones, with some areas downgraded from First to Third Degree Archaeological Site status due to extensive modern development(Fig. 8).
- Today, Side remains a unique cultural landscape where ancient ruins and a living settlement coexist, requiring ongoing and adaptive conservation strategies.

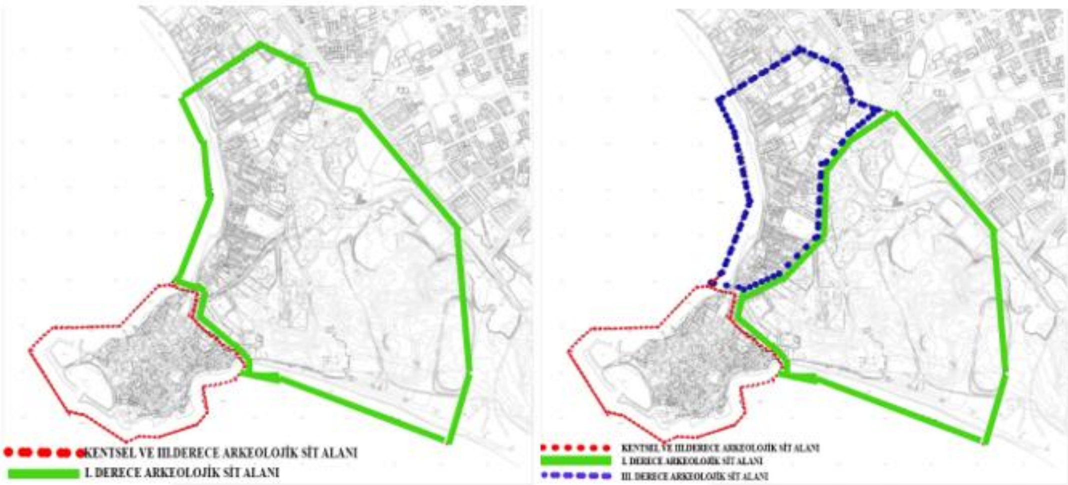

Fig. 8. 2012 Boundaries of the Ancient City of Side Archaeological Site (Left), Current Site Boundaries (Right)

2.2.3. Conservation Problems Experienced in the Mixed-Use Site Area of Side

In the 1960s, efforts were initiated to promote tourism along Turkey's Mediterranean coast, and governmental ministries developed policies to attract foreign tourists. In 1969, an international competition was organized for the planning of Side and its surroundings. As a result, Side became a major attraction, particularly during the 1980s. Rapid urban development driven by tourism, however, led to unplanned impacts on cultural heritage. The economic benefits of tourism began to outweigh the preservation of cultural values, resulting in uncontrolled construction.

- One major issue was the lack of timely intervention to protect cultural assets and the failure to implement conservation plans. This was largely due to the lack of institutional cooperation and each authority attempting to implement its own plans. For instance, in 1993, the conservation work proposed by the Side Municipality was rejected by the Antalya Conservation Board, and in 1995, the Side Municipality rejected the Antalya Board's revision of the Conservation Master Plan. Consequently, interventions to protect the ancient city were delayed, and the rate of damage increased.
- The conservation studies failed to address the needs and challenges of contemporary life, reducing their effectiveness. Uncontrolled tourism growth, combined with inadequate planning, significantly harmed natural and cultural assets (Sağıroğlu, 2016, pp. 555–560). Tourism development efforts (1969) began earlier and received more attention than conservation initiatives (1982), leaving the ancient city vulnerable. Tourism projects attracted investors, leading to the purchase of properties from local residents (Yıldırım, 2013, p. 158).
- In 1976, the Real Estate Antiquities and Monuments Board created conservation zones for Side. In 1982, the area was divided into the village center and the necropolis zone, allowing for new constructions compatible

with the traditional texture in the village center. However, this permission led to increased construction within the ancient city, conflicting with conservation principles (Büyüksural & Sağıoğlu Demirci, 2023).

- Although later conservation master plans initiated legal actions against unauthorized structures, inconsistent decisions weakened enforcement. For example, within a single parcel, construction was permitted on one part but prohibited on another, leading to court cases and further legal uncertainty (Boyacıoğlu, 2011).
- The 1998 Side Conservation Master Plan Revision allowed construction close to and even above archaeological remains (Fig. 9).

Fig. 9. New structures built within the archaeological site

- In 1999, the Antalya High Conservation Council prohibited interventions in first-degree archaeological sites, except for scientific research, but earlier construction permissions created conflicts.
- Traditional Side houses, typically one or two stories high, were affected by 1999 planning changes that increased the building height from 6.5 meters to 9.5 meters, promoting the transformation of residential areas into tourism facilities (Alparslan & Ortaçeşme, 2009, p. 170). As a result, taller structures emerged, disrupting the traditional silhouette.
- Economic shifts led locals, traditionally engaged in agriculture, livestock, fishing, and olive cultivation, to adapt their buildings for tourism, causing the loss of architectural authenticity. Adaptive reuse efforts often neglected the original character of structures, impeding cultural sustainability. Additionally, high-volume events held near ancient temples ignored potential structural impacts.
- Due to urbanization pressures, the ancient city could not be preserved as a whole, and monumental structures became isolated (Büyüksural, Karamağaralı, & Sağıoğlu Demirci, 2022).

Although the 2014 Conservation Master Plan marked significant steps toward preservation, it struggled to address how to balance the protection of archaeological values with ongoing contemporary life. In multi-layered urban fabrics like Side, prioritizing certain values over others has weakened the overall integrity. Side embodies both the traditional settlement developed by Cretan immigrants in the 20th century and Roman urban planning, requiring a holistic conservation approach that considers all layers and values. Conservation strategies must be comprehensive and carefully analyze the impacts of tourism.

3. Evaluation and Conclusion

Table 3. Problem Definition and Evaluation

Problem Identification	Evaluation
Akdamar Mixed Site Area	
The island, registered as a 1st-degree natural and archaeological site, was re-evaluated under the regulation published in 2012 and reclassified as a Qualified Natural Conservation Area on May 3, 2019. Although the island retained its characteristics, its classification was downgraded from 1st degree to 2nd degree under the new law.	In cases where site areas of different statuses overlap, all natural, historical, archaeological, and urban values of the area must be thoroughly examined, and a holistic approach must be adopted to ensure the protection of each value.

Table 3.continued

Problem Identification	Evaluation
After the authority and responsibility for natural site areas were transferred to the Ministry of Environment and Urbanization in 2011, deficiencies in authority sharing and coordination in mixed site areas became evident. As Akdamar Island contains both natural and cultural values, these deficiencies have been more strongly felt in the area. Due to overlapping jurisdictions, inconsistencies in decision-making have disrupted conservation and management processes.	In cases where different protection areas overlap, protocols should be prepared to ensure inter-institutional cooperation and to reduce management and authority-related issues between institutions.
The opening of Akdamar Island to visitors and the intensification of tourism activities have placed significant pressure on the natural and cultural resources of the area. Issues such as increased physical wear, environmental pollution, and the deterioration of the natural landscape caused by high visitor density make long-term conservation of the site more difficult.	A comprehensive planning and visitor management strategy must be developed to regulate tourism use.
The absence of a regulation in the current legislation for the protection of mixed site areas leads to the separate evaluation of site types. This situation results in the lack of a holistic approach in the conservation of mixed site areas. When personal opinions take precedence and this is combined with a lack of interdisciplinary cooperation in developing conservation strategies, a balance between the natural and cultural elements of Akdamar Island cannot be achieved.	In order to effectively protect the natural and cultural values of Akdamar Island, the current legislation must be reviewed, and mixed site areas must be evaluated through a holistic approach. In this context, an interdisciplinary conservation strategy must be adopted.
As part of Akdamar Island's UNESCO nomination process, the island was included in the UNESCO Tentative World Heritage List in 2015 following a submission that highlighted only its cultural heritage features under the title "Akdamar Memorial Museum (Church)."	This imbalance experienced during Akdamar Island's UNESCO process necessitates the development of integrated strategies that ensure equal protection of both natural and cultural values. In this context, submitting the site as a mixed property would provide a more comprehensive framework for conservation.
Side Mixed Site Area	
The failure to protect the cultural values of the rapidly developing city due to the lack of timely intervention and the inability to implement the prepared conservation plans. The reason for the failure to implement these plans is the lack of inter-institutional cooperation and the desire of each institution to implement its own plan.	In mixed site areas, practices should be developed to ensure inter-institutional cooperation and enable institutions to produce plans on a common ground.
Due to the mismanagement of uncontrolled tourism-driven development, areas without conservation plans have been significantly affected, leading to damage to natural and cultural values before they could be protected.	To protect, manage, and ensure planned development in regions with high tourism potential, site-specific policies should be developed.
In 1982, Side was evaluated in two zones: the village center and the necropolis area. In this study, permission was granted for new constructions in the village center that were compatible with the historical fabric. However, inadequately prepared conservation efforts led to irreversible impacts.	Conservation efforts must be prepared with sensitivity to site-specific conditions, ensuring that they do not allow practices that could pose problems within the regulatory framework.

Table 3.continued

The local population, whose livelihood depended on agriculture, livestock, fishing, olive cultivation, etc., began to alter their traditional buildings to benefit from tourism potential, leading to the loss of architectural and structural authenticity.	Approaches appropriate to the site's potential should be adopted, and planning should include considerations that do not overlook social life.
As buildings began to transform with tourism, their original conditions were disregarded during adaptive reuse, hindering the cultural sustainability of the structures.	When restoring buildings, the new functions assigned should be original or closely related to the original. Functions that would significantly alter the building's layout or façade should not be permitted.

Mixed heritage sites, which encompass multiple types of heritage simultaneously, require that conservation efforts address all values in a holistic manner rather than focusing on individual heritage types. However, it has been observed that this holistic conservation approach is not fully achieved in the current practices in Turkey. For example, in the Side Ancient Settlement, archaeological values are overlooked in areas designated as urban heritage sites, while in Van Akdamar Island, natural values are inadequately protected during the prioritization of cultural values. This situation reveals that a balance between the values that constitute the different layers of the site has not been established, and therefore, holistic conservation has not been effectively implemented.

In Turkey, the overlap of heritage sites with different qualities is quite common. However, there is a lack of a clear definition of mixed heritage sites in the legislation, and the protection and usage conditions for these sites are not well defined. This deficiency makes it difficult to establish protection policies in cases where heritage sites of different types overlap. In mixed heritage sites, the values associated with each heritage type should be addressed separately, and a protection strategy should be developed that covers all layers and characteristics of the site. This approach will ensure the protection of archaeological, cultural, natural, and urban values while also facilitating the harmonious transmission of these values together.

The legislation should be revised to explicitly and clearly express protection approaches for mixed heritage sites. Additionally, detailed regulations should be developed to prevent uncertainties during the implementation processes, and these regulations must be strictly enforced to prevent irreversible damage. Otherwise, serious consequences may arise, such as the destruction or complete loss of one heritage site while protecting another. In order to ensure the sustainable protection of mixed heritage sites, planning should be conducted using a holistic approach, which is critical for transmitting the site's multifaceted values to future generations.

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The Impact of climate change on stone structures: An evaluation of the Yakutiye Medrese in Erzurum

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Abstract. Climate change has begun to show its effects in various fields both globally and in our country in recent years. The impacts of climate change pose serious threats to our cultural heritage, especially in buildings constructed with stone materials. Environmental factors such as temperature fluctuations, freeze-thaw cycles, and increased humidity directly affect the physical and chemical structure of stone materials, leading to various forms of deterioration in these buildings. Deterioration, such as cracking, surface wear, color changes, and general structural weakening, not only threatens the aesthetic value of these buildings but also weakens their structural stability. If necessary precautions are not taken, this can result in irreversible damage. In this context, Erzurum, known for its harsh and cold climate, creates significant effects on historical structures, especially when combined with the region's continental conditions. A striking example of this is the Yakutiye Medrese, which is constantly exposed to these challenging climatic conditions. In light of scientific studies and analyses conducted on the city's climate and climatic variables, the aim of this study is to assess the effects of environmental threats arising from climate change on historical buildings, with a particular focus on the Yakutiye Medrese in Erzurum. The archival research to be carried out in this context is expected to play a critical role in tracking cultural continuity and in developing preventive measures and conservation strategies to mitigate the effects of climate change. These efforts are of vital importance in ensuring the long-term preservation of cultural heritage.

Keywords: Climate change; Stone structures; Erzurum; Yakutiye Medrese; Conservation strategies

1. Introduction

Changes occurring in nature have influenced societies for centuries. The historical processes, economies, population statuses, and migration movements of cities have been shaped as a reflection of what nature provides us. At the forefront of these factors is 'climate' (Gürsul & Yeler, 2022). Climate is the most fundamental factor determining the living spaces and characteristics of living beings and is a source that meets all of humanity's needs. Climate change emerges as a global issue that could lead to serious environmental and socio-economic consequences. Considering Turkey's geographical location, it is evident that our country is among the regions at risk for the potential impacts of climate change (Davarcıoğlu & Lelik, 2018).

The impact of climate on urban memory and morphology has become more pronounced since the 20th century. In addition to natural factors, human activities and industrialization, which increased with the Industrial Revolution, led to a rise in carbon emissions and the amount of greenhouse gases released into the atmosphere. This has brought the concept of 'climate change' to the forefront of global issues that require urgent solutions (Gürsul & Yeler, 2022). The Intergovernmental Panel on Climate Change (IPCC), established in 1988 (URL-1, 2025), emphasizes in its 2022 report "Climate Change: Impacts, Adaptation, and Vulnerability" (Türkeş, 2022) that without necessary measures, the impacts of climate change could result in irreversible consequences (URL-2).

The threat of climate change, which manifests in social, economic, and ecological fields, also has a profound impact on historical structures and their surroundings, which play an important role in preserving cultural continuity. Many international conservation organizations, such as the International Council on Monuments and Sites (ICOMOS) and the UNESCO World Heritage Centre (WHC), are examining the effects of climate change on cultural heritage and working on measures to mitigate these impacts. However, the threat that climate change poses to cultural heritage was acknowledged at the 29th General Assembly of WHC held in 2005 (Colette, 2007; Gürsul & Yeler, 2022).

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The increasingly evident threat of climate change on our cultural heritage requires us to reshape our approaches in conservation and develop solution-oriented strategies. This study examines the effects of climate change in the Erzurum province and its surroundings on the Yakutiye Medrese, and proposes various measures to mitigate these impacts, along with solutions for the preservation of the historical structure.

2. Materials and Methods

2.1. Materials

The research area of this study, which aims to examine more thoroughly the effects of climate change on stone structures, consists of the province of Erzurum and the historical Yakutiye Medrese located within its boundaries. As research materials, the study will utilize climatic data specific to Erzurum, meteorological reports, scientific studies on long-term climate change, archival documents obtained from the Erzurum Regional Board for the Conservation of Cultural Heritage (EKVKBKM) regarding the Yakutiye Madrasa, and other scholarly research conducted on the structure.

2.1.1. Location and History of Erzurum and the Medrese

Erzurum is located in the northeastern part of the Eastern Anatolia Region, in the Erzurum-Kars section. The province is bordered by Kars and Ağrı to the east, Rize and Artvin to the north, Gümüşhane and Erzincan to the west, and Bingöl and Muş to the south. In terms of topography, the land is mainly covered with mountains, plateaus, and plains (URL-3, 2025). With its favorable natural conditions and geographic location (URL-4, 2025), Erzurum has been home to various civilizations throughout history (Demlikoğlu, 2013), and is one of the most rooted cities in Anatolia due to its strategic and cultural significance (Kutlu, 2016; Demlikoğlu, 2018) (Fig.1.).

This city, notable for the advantages of its location and the valuable heritage brought by the civilizations it hosted, has become an important stop for tourism. The cultural heritage that reflects the history of the city continuously enhances its significance in the field of cultural tourism. One of these heritage sites is the historical 'Yakutiye Medrese,' located in the city center and currently used as a museum (Temur & Açıcı, 2022).

The Yakutiye Medrese was built during the reign of the Ilkhanid ruler Olcaytu Hüdabende in the 14th century (1310-1311) by Emir Cemaleddin Yakut, on behalf of Gazan Khan and Bolugan Hatun. It is located in the city center of Erzurum, on Cumhuriyet Avenue, to the west of Lala Paşa Mosque (Fig.1.). The inscription on the main gate of the medrese contains information about the construction date and those who ordered the building. According to the Arabic inscription's translation, it says: "This medrese was built in the year 716 H. (1316 M.), during the reign of Ulcayto Sultan, 'May Allah make His kingdom eternal,' according to the noble and beautiful beliefs of Sultan Gazan and Bolugan Hatun, 'May Allah illuminate their proofs.' It was built with the income (money) by Cemaleddin Hoca Yakut-i Gâzâni." The Yakutiye Medrese, one of the largest closed-courtyard madrasas in Anatolia, is one of Erzurum's most impressive buildings with its architectural plan, balanced structure, and large decorative motifs. It is currently used as the Turkish-Islamic Art and Ethnography Museum (Erzurum Provincial Socio-Economic Profile, 2018; Temur & Açıcı, 2022).

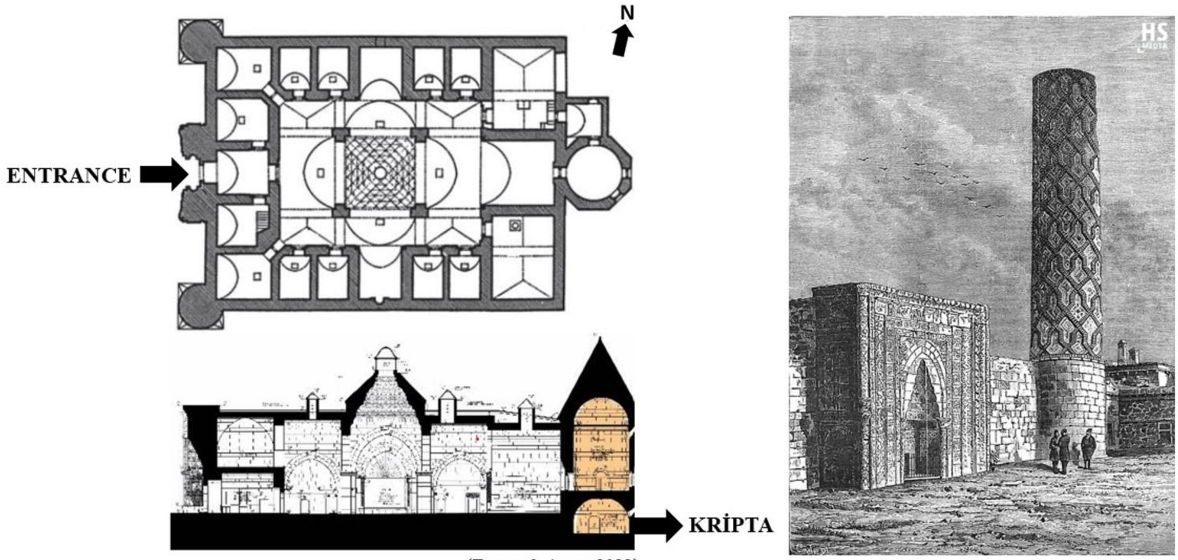
Fig. 1. The Location of the Study Area on the Map of Turkey

2.1.2. Architectural and Material Features of Yakutiye Medrese

The Yakutiye Medrese is rectangular in shape, measuring 33.4 m x 24.4 m, with a large courtyard in the center. The medrese, which has a closed courtyard, is a one-story building with three iwans, arcades, and a large structure. However, a second floor is present only in the entrance iwan (Fig.2.). The main entrance of the building is on the western façade. From the entrance gate of the medrese, a vaulted corridor leads to an inner area, which is higher and connects with another vaulted area. There are columns in the corners of the structure. The building is constructed with a central dome resting on four columns, surrounded by half domes and large arched roofs in the east-west direction. The main dome is built on a square area measuring 7.75 m, with a height of 12.9 m. There are two minarets at the northwest and southwest corners of the medrese, standing at heights of 21.2 m and 8.25 m, respectively. In the iwan on the eastern façade of the medrese, a tomb stands on a square pedestal, topped with a twelve-sided conical dome. Stairs in this area lead to the crypt (cenazelik) below (Fig.2.) (Kocaman et al., 2018; Temur & Açıcı, 2022).

The thickness of the main walls of the medrese is approximately 130 cm, and the walls rise to 7.6 m on all sides. The walls, which bear the weight of the domes, were built using a filler wall system, called "three-leafed," with bonding materials between cut stones (Kocaman et al., 2018; Temur & Açıcı, 2022). Except for the minaret's body, stone materials were used throughout the structure. The exterior of the building, including the supporting and roofing elements (arcade columns and arches, iwan walls and vaults, domes, door arches, and frames of the rooms), is covered with neatly cut stones. The interior walls and vaults of the rooms are made of rubble stone, which has been plastered later. The conical dome of the tomb is covered with red volcanic stone (andesite), locally known as "Kamber stone," which is a regional material seen in other tomb structures in Erzurum (Eskici et al., 2006) (Fig.2.).

This structure, which was used as a foundry during the Ottoman period, is known to have been used as a military depot from the late 19th century to the early years of the Republic. The building has been restored three times by the Directorate General of Foundations (1964-1973) and the Ministry of Culture (1991) during the Republic period (Kocaman et al., 2018; Temur & Açıcı, 2022).



(Temur & Açıcı, 2022) (URL-5, 2025)

Fig. 2. Yakutiye Medresesi (Temur & Açıcı, 2022; URL-5, 2025)

2.1.3. Climate Change in Erzurum

Global warming leads to temperature increases worldwide, causing climate change. Climate change is generally defined as long-term and gradually evolving changes that create large-scale and locally significant impacts on weather conditions. One of the most noticeable effects of these changes is the irregularity in precipitation patterns; the rise in temperatures increases evaporation, promoting droughts and irregular rainfall. Rising temperatures also reduce snowfall. The decrease or complete disappearance of snowfall will have significant consequences for hydrological cycles (Karaman & Gökalp, 2010). It is, of course, impossible to limit the effects of climate change to just primary parameters such as temperature and precipitation. As global temperatures rise, this directly affects wind systems as well. Particularly with the warming of oceans and land surfaces, temperature differences in the atmosphere change, which can affect the intensity, direction, and speed of winds. These changes can lead to significant shifts in local and global climate models (Gürsul & Yeler, 2022).

Erzurum, located in the northeast of the Eastern Anatolia Region, has a unique and characteristic climate due to its morphological features and geographical location. With very cold and snowy winters, and hot and dry summers, Erzurum has a continental climate (Erzurum Province 2023 Environmental Status Report, 2024), and climate deviations have occurred over time. According to Meteoblue data, a noticeable increase in air temperatures has been observed in Erzurum between 1980 and 2024. The average temperature in 1980 was 5.9°C, while it reached 7.7°C in 2024 (Fig.3.). Additionally, the annual precipitation amount has decreased from 629.6 mm in 1980 to 608.3 mm in 2024, clearly indicating that rainfall has decreased and become more irregular (Fig.4.). Erzurum's climate is not immune to global climate change, and like many regions around the world, it is facing fluctuations and reductions in rainfall (URL-6, 2025). These changes leave deep and lasting marks on Erzurum's ecosystem, negatively affecting snow quality and the duration of snow cover on the ground. On average, the ground in Erzurum is covered with snow for 107 days, but between 1931 and 2018, this period decreased by 21 days (Fig.5.). During this time, the snow height also decreased by 17% (Fig.6.). These dramatic changes significantly affect the region's climate balance and natural life, leading to a transformation in Erzurum's ecological structure.

Limiting the effects of climate change to basic parameters such as temperature and precipitation is insufficient to fully comprehend the depth of this global phenomenon. In regions like Erzurum, the increase in high temperatures has visibly raised evaporation rates, leading to serious disruptions in the moisture balance. As a result of these changes, there have been noticeable shifts in wind patterns and intensity, with atmospheric movements taking a different direction. Erzurum's 88 years of climate data reveal a significant increase in annual average wind speed. The data show a 6.7% upward trend in the long term, with the annual average wind speed rising from 8.8 km/h (Fig.7.). This is a clear indication that wind movements, as well as temperature and precipitation, are evolving as a reflection of climate change (Toy & Türkeş, 2022).

Moreover, the effects of air pollution form another significant aspect of this process. Over time, polluted air causes severe deterioration and permanent stains on building facades, accelerating the corrosion process of construction materials. Pollutants such as sulfur dioxide (SO_2) increase the concentration of acidic compounds in the atmosphere, posing a serious threat to the durability of structures. The effect of these pollutants accelerates the corrosion of materials like metal and stone, shortening the lifespan of buildings. On the other hand, the decrease in rainfall, which functions as a natural air pollution cleanser, exacerbates the situation. While rainfall helps to reduce harmful components in the air by bringing pollutants to the ground, the weakening of this natural cleaning process leads to further deterioration of air quality and an increase in the negative environmental impacts (Karaca et al., 2013).

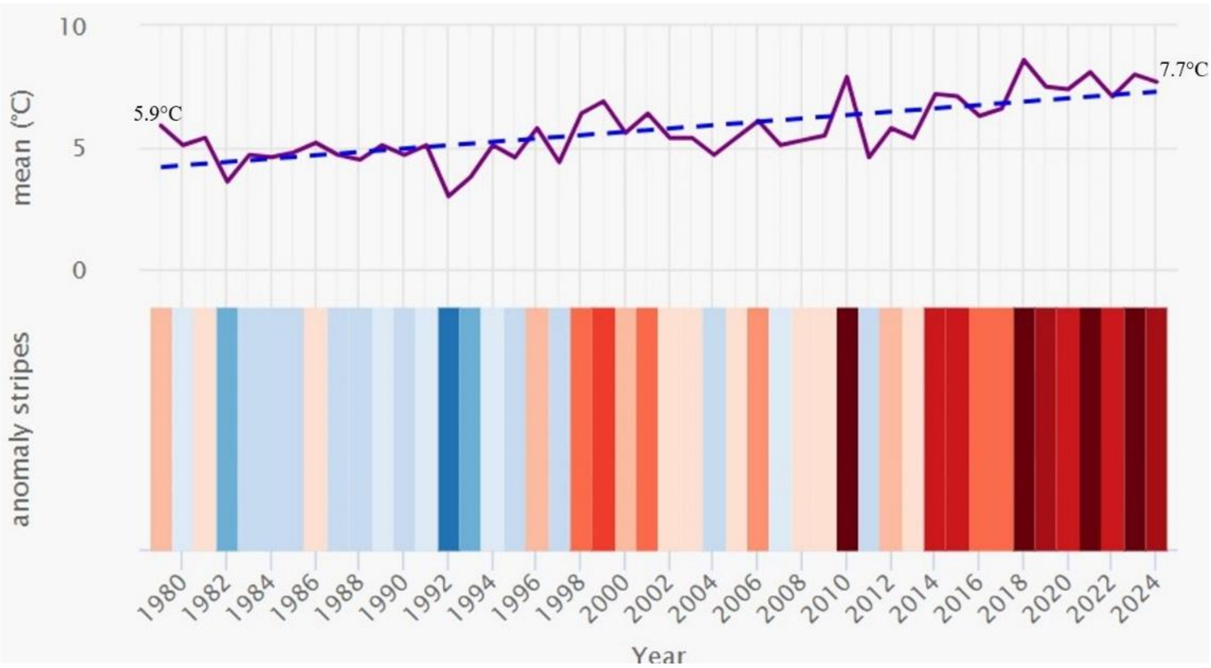


Fig.3. Temperature Change by Year (URL-6, 2025)

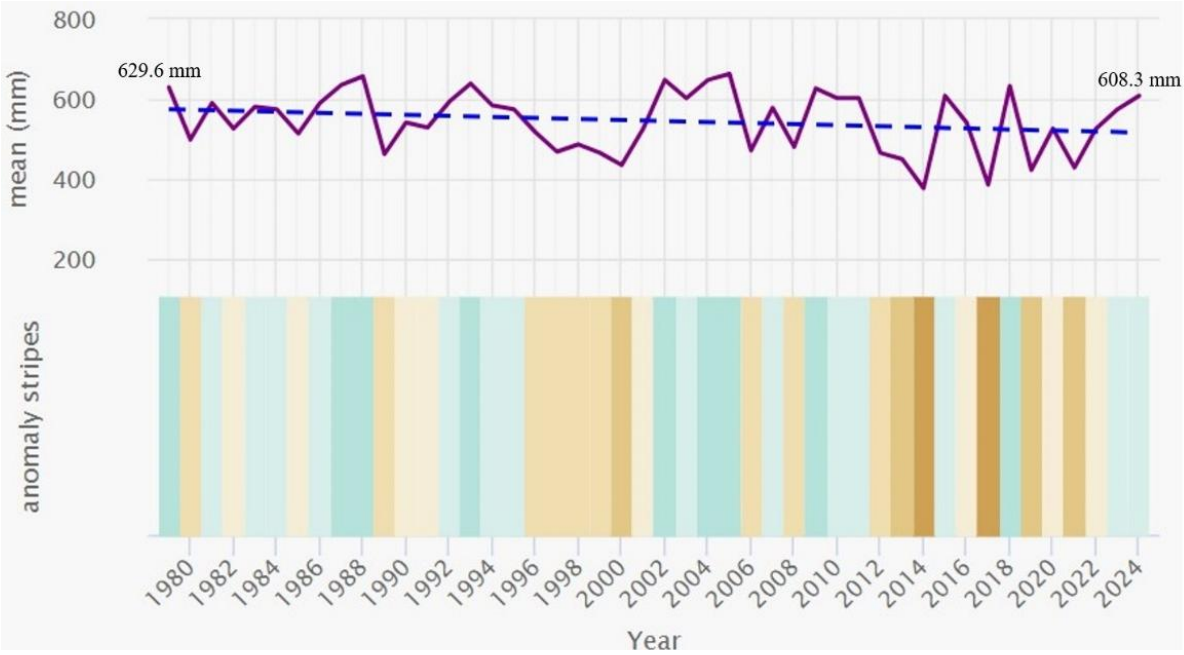


Fig.4. Precipitation Change by Year (URL-6, 2025)

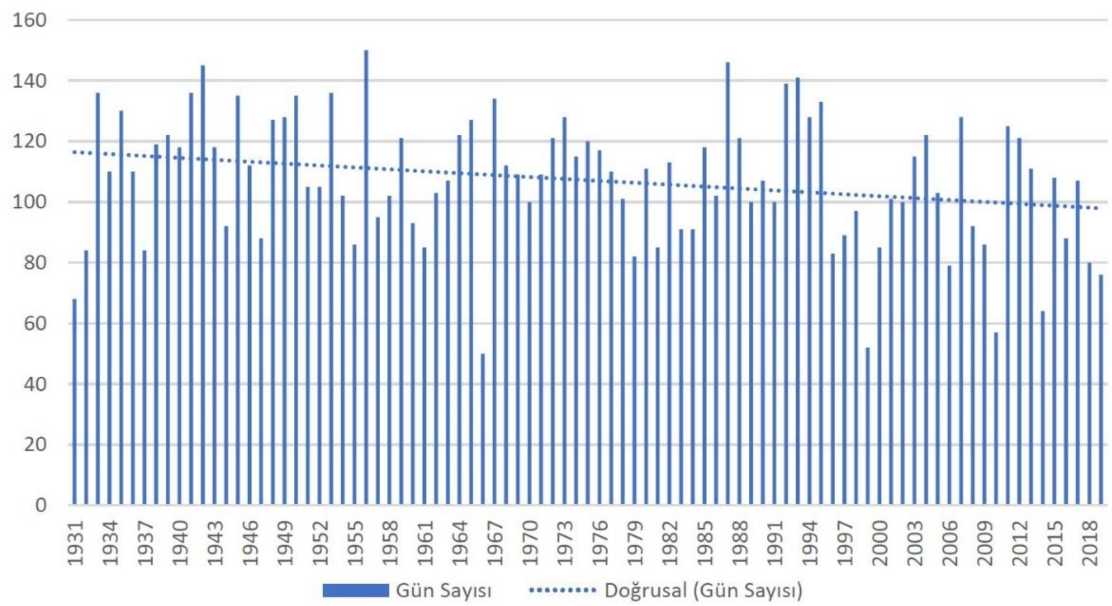


Fig.5. Snow-Covered Days Analysis (Toy & Türkeş, 2022)

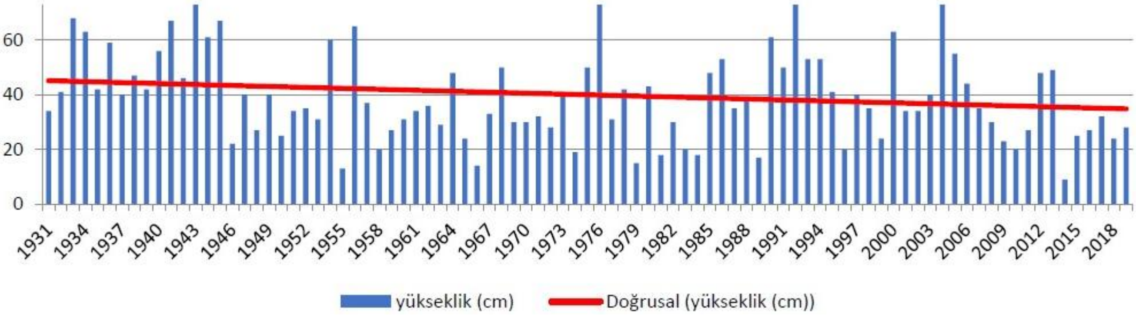


Fig.6. Snow Height Analysis (Toy & Türkeş, 2022)

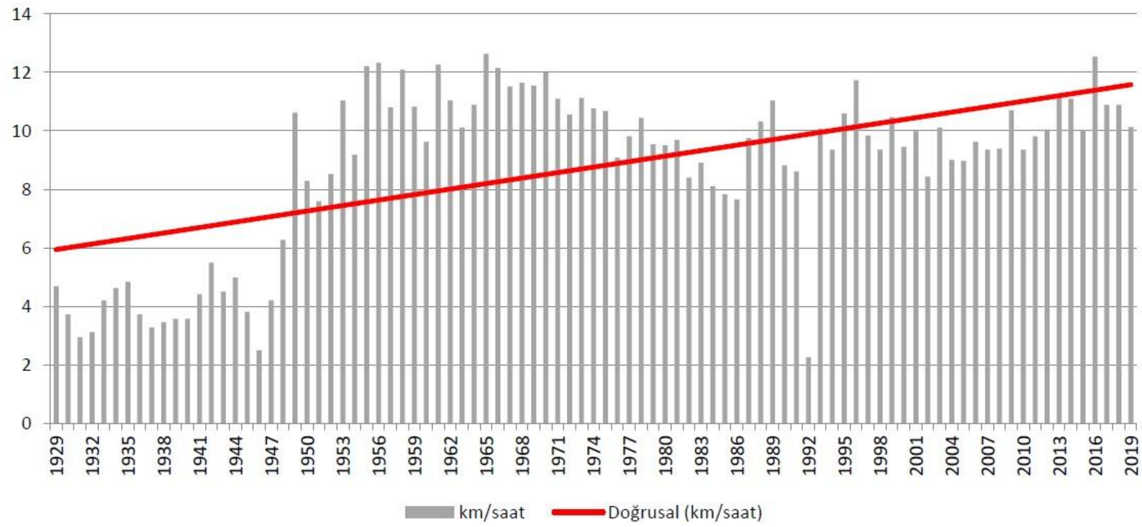


Fig.7. Wind Speed Analysis (Toy & Türkeş, 2022)

2.2. Methods

This study, aimed at examining the effects of climate change on Yakutiye Medrese, consists of three different stages:

- Archive Research and Visual-Structural Examination: In the first stage, a comprehensive archive research was conducted on the medrese, followed by a visual and structural examination of the building.
- Analysis of Climate Data: To better understand the impact of climate change on stone structures in Erzurum, long-term climate data (temperature, humidity, precipitation, and freeze-thaw cycles) for Erzurum province were analyzed. Special focus was given to the climate changes over the last 30 years.
- Evaluation of the Relationship Between Climate and Deterioration Processes: In the final stage, the relationship between climate data and the deterioration processes of stone structures was examined in detail, highlighting the connection between these two factors.

3. Findings and Discussion

Climate change, particularly in the form of drought, has a profound impact on climatic variables, leading to significant negative effects. These impacts manifest both directly and indirectly, making the problems caused by climate change more complex. On an international level, the risks associated with climate change are generally assessed from environmental, societal, biophysical, and economic perspectives. However, historical structures and their surroundings, which play a crucial role in preserving cultural heritage, should not be excluded from this scope. This is because the effects of climate change can indirectly impact these elements, which are vital for ensuring cultural continuity (Gürsul & Yeler, 2022). In this context, international efforts in the field of conservation are based on the 2004 International Scientific Committee meeting organized by the International Council on Monuments and Sites (ICOMOS), followed by the 29th General Assembly of the UNESCO World Heritage Centre (DMM) in 2005. Since then, international organizations in this field have created various working groups to understand the threats of climate change to cultural heritage and develop solutions. Through the reports they published, they have tried to raise public awareness about the preservation of cultural heritage. Changes in temperature, rainfall, atmospheric humidity, wind intensity, as well as the interaction between sea level rise (SLR), desertification, climate change, and air pollution have been defined by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as threats to cultural heritage (Sesana et al., 2021). In 2019, the ICOMOS Climate Action Working Group published an important report titled "The Future of Our Past: The Role of Cultural Heritage in Climate Action." This report deeply explored the impacts of climate change on archaeological sites, collections, historical buildings, cultural landscapes, traditional communities, and intangible cultural heritage, aiming to evaluate the vulnerability of heritage in the face of these impacts and to develop new methods and tools for its preservation. Additionally, the report argued for the establishment of a stronger connection between climate change and the preservation of cultural heritage, asserting that a bridge should be built between these two areas (Gençer, 2022).

Considering that these two areas complement and influence each other, the challenges faced by historic stone structures due to climate change pose serious threats not only to their structural integrity but also to their aesthetic values. Due to the effects of climatic changes, the material components, external surfaces, and overall durability of historical stone buildings may weaken over time, leading to greater damage. The city of Gubbio in Italy, built on a hill, has historically experienced the effects of more frequent and intense rainfall on its stone walls. The city's walls have been damaged by landslides, and the erosion of the mortar between the stones has led to the stones falling off. Gubbio is also famous for its Palazzo dei Consoli, built in the 14th century, which is the city's most iconic building and hosts art and archaeological exhibitions. However, more frequent and intense rainfall has caused cracks in the stone walls of the building, raising concerns. Similarly, the walls of Koules Castle, located in Crete and built by the Genoese in the 16th century on the seafront, are constantly eroding due to the waves that hit them (URL-7, 2025). This clearly illustrates the negative impact of climate change on stone structures, affecting wind direction and wave intensity. In this context, to deeply understand the negative effects of climate change on cultural heritage, it is crucial to be informed about the damaging factors in the literature and the consequences of these damages. The table presented below will further clarify which factors contribute to these negative effects and how they threaten our cultural heritage (Table 1.).

The examined scientific studies reveal that the primary effect of climate change observed in the Erzurum province is the rise in temperature, which has led to significant deterioration, particularly on stone structures. One of the most affected buildings is the Yakutiye Medrese, which is among the important historical structures of Erzurum. The stone materials used in the medrese have been subjected to thermal stress due to the increasing temperatures. As a result, pressure stresses have occurred on the stone surfaces of the medrese during extreme heat, while tensile stresses have emerged during cold weather. The constantly changing temperature fluctuations have weakened the integrity of the stones, leading to deep cracks, fracures, and even loss of pieces on the surface (Fig. 9-10).

Another impact of climate change is the fluctuations in precipitation. These fluctuations in both rainfall and temperature have negatively affected the quality and duration of snow cover in Erzurum. The snow melts earlier than expected, and the insufficient drainage system in the area causes more water to penetrate and accumulate in the stone material. Specifically, water accumulation within the internal structure of the stone material has led to wear, and the movement of water within the stone material has caused salt deposits to form on the surface. Additionally, with the rapid melting of snow, vegetation has started to grow on the stones (Fig. 11).

In addition, with the landscaping adjustments made in 2008, the large trees in front of the Yakutiye Medrese were removed (Fig. 12-13). The absence of the trees has increased the effect of stronger winds, which have intensified due to climate change, impacting the Yakutiye Medrese. This has caused the joints between the stone materials of the medrese to erode, leading to gaps over time. Furthermore, due to decreasing rainfall and increasing drought in recent years, dust and dirt carried by the wind have settled on the stone surfaces of the building. These dust particles have left traces on the texture of the stones, leading to their gradual deterioration (Fig. 14).

As a result of the impacts of climate change, the deteriorations observed in the stone materials of the Yakutiye Madrasa have been examined in detail. The specific parts of the structure where these deteriorations have occurred were systematically classified and numbered on technical drawings. Each type of deterioration was documented based on on-site observations and presented with supporting visual materials (Fig. 8).

Table 1. Causes and Results of Damage Caused by Climate Change

Cause of Damage	Result of Damage
Sudden fluctuations in temperature and humidity	Expansion and contraction in building materials; cracks, breakages, and loss of pieces on surfaces.
Drought	Landslides and settlement in the foundation soil; damage to building materials due to disrupted moisture balance.
Excessive rainfall and flooding	Flooding of buildings; mold and mildew formation on walls and facades due to increased moisture.
Storms and hurricanes	Damage to structural elements of buildings; collapse or detachment of roofs and facades.
Sea level rise	Submersion of historical buildings on the coast; damage to building materials from salty water.
Air pollution	Pollution on the stone surfaces of historical buildings and deterioration of materials over time due to corrosive (wearing) effects, color change (Sesana et al., 2021).

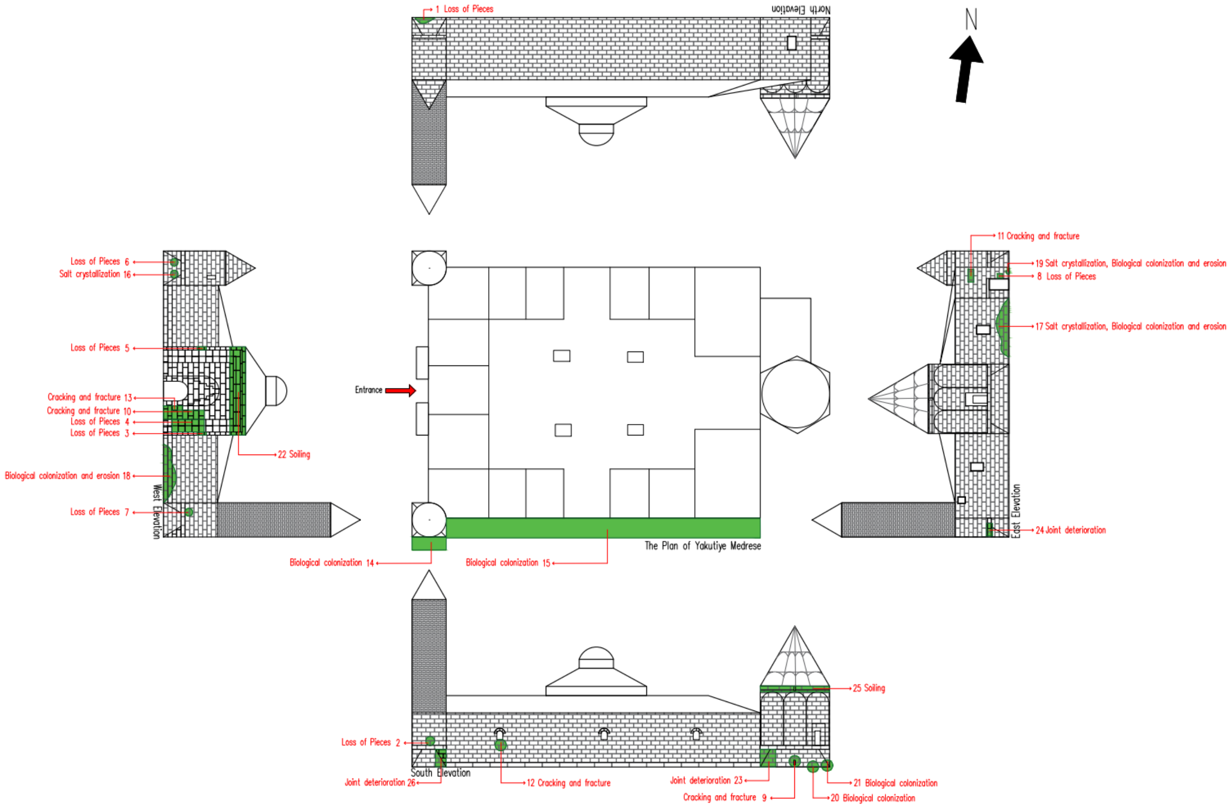


Fig. 8. Depiction of the Deterioration of Stone Elements in Yakutiye Medrese on sketch (Drawn by the Author)

Fig. 9. Loss of Pieces in the Stone Material of the Yakutiye Medrese (Author Archive, 2025)

Fig. 10. Cracking and fracture in the Stone Material of the Yakutiye Medrese (Author Archive, 2025)

Fig. 11. Erosion, Salt Crystallization, and Biological Colonization on the Stone Material of the Yakutiye Medrese (Author Archive, 2025)

Fig. 12. The Image of the Yakutiye Medrese and its Surroundings with the Tea Garden and Trees in 2006 (EKVKBKM, 2021)

Fig. 13. Current View of Yakutiye Medrese and Its Surroundings (Author Archive, 2025)

Fig. 14. Joint deterioration and Soiling on the Stone Material of the Yakutiye Medrese (Author Archive, 2025)

4. Conclusions and Recommendations

Climate change, which has had profound effects on the geographies and societies around the world for centuries, has gained increasing global importance, particularly since the 20th century. With the unconscious increase in human activities, this impact has also begun to strongly manifest itself in our country. In light of scientific research conducted in the Erzurum province, the traces and effects of climate change in this region are clearly observable. Studies and analyses on urban climate and climatic variables highlight rising temperatures, irregular rainfall, changes in wind speed, a decrease in snow cover duration, drought, and air pollution in the city. These effects of climate change are also negatively impacting Erzurum's historical texture. The Yakutiye Medrese in Erzurum serves as an example of this adverse impact. One of the most important historical structures in Erzurum, this medrese has been exposed to both human-induced destruction and changing natural conditions. Cracks, breakages, splits, piece losses, and joint gaps observed in the building and its façades are significant risks that threaten the structural integrity of the building. Furthermore, deterioration such as salting, vegetation growth, and surface wear is gradually causing damage to the physical structure of the medrese. Frescoes, decorations, and inscribed stones in both the interior and exterior have experienced damage, including pollution, flaking, and detachment. A comprehensive and scientific approach is required for the preservation of the Yakutiye Medrese and to prevent these damages. The first steps in this process should include identifying the risks within the building, evaluating their impacts, and determining effective conservation methods. The damages observed in the medrese, such as cracks, material and surface losses, and joint gaps, indicate that conservation efforts should be prioritized to prevent the loss of this important cultural heritage. To protect the building, the material structure and chemical properties of the stone should be thoroughly examined. Specifically, the darkening observed on the stone material requires sensitive intervention. In this regard, modern and careful techniques such as laser cleaning could be applied. Additionally, for vegetation growth and potential pests in the building, mechanical methods could be suggested rather than chemical interventions. Chemical substances could damage the historic materials and further jeopardize the structural integrity of the building. Arrangements around the Yakutiye Medrese are also of great importance.

Based on the old sources and documents, replanting the area surrounding the building with trees that are historically appropriate and restoring the natural vegetation will create an environment that aligns with the medrese's historical texture. After this restoration process, the effects of climate change on the building should be scientifically determined, and adaptation strategies should be developed accordingly. Periodic control and maintenance processes must be meticulously implemented. Long-term conservation efforts should not be limited to physical restoration. Additionally, adaptation strategies, shaped by scientific data, should be created to mitigate the effects of climate change in the region. The preservation of historical buildings in Erzurum is not only a local responsibility but also crucial for ensuring the continuity of global cultural heritage. National and international conservation principles will have a positive impact on transferring the preservation of such structures to future generations and ensuring that they protect this cultural heritage.

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Fire risk assessment methods for historical buildings

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Abstract. Historical buildings refer to buildings located within conservation areas designated by local and international institutions or within traditional contexts, possessing significant architectural or historical value. These buildings represent the cultural and architectural heritage of humanity and serve as key symbols shaping the identities of societies. However, these valuable assets are exposed to both natural and human-induced threats. Among these, fires stand out as one of the most devastating events capable of destroying such buildings. Fires often cause not only significant material losses but also the loss of cultural heritage.The impact of fires on historical buildings is not limited to material losses. These buildings are often living witnesses of history, art, and culture. The destruction of historical buildings in fires harms the shared heritage of societies and humanity. Analyzing past fire incidents involving historical buildings reveals that these buildings, due to the lack of widespread fire engineering and inspection practices during their construction periods, are particularly vulnerable to fire because of their construction systems and material choices. Various Fire Risk Assessment (FRA) methods are used to evaluate the fire resistance of these buildings in their current state. However, historical buildings require a distinct assessment method due to their unique characteristics. In this context, the study analyzes existing FRA methods, discusses the factors that should be considered for risk assessment specific to historical buildings, and highlights the strengths and/or shortcomings of these methods in comparison to one another.

Keywords: Historical buildings; Fire; Risk analysis; Assessment method; Fire risk assessment.

1. Introduction

Fire can be simply defined as the rapid oxidation of a substance involving heat and light. In general, oxidation is the chemical combination of any substance with oxygen. Heat is also produced from this combination, but it is very difficult to measure because it is so small. Fire can usually only occur when three things are present: oxygen in some form, fuel (material) that will combine with the oxygen, and sufficient heat to sustain combustion. Removing any one of these three factors will result in the extinguishing of the fire. The classic "fire triangle" is a graphical symbolization of the known elements involved in the combustion process (Fig. 1). Opening the triangle by removing one factor will extinguish a growing fire, and preventing any one factor from joining the other two will prevent the fire from starting.

Some studies in the literature show that this chemical reaction cannot consist of only these three factors. According to Haessler (1974), a fourth factor, the "reaction chain", was determined and it is stated that this factor starts from the moment the combustion starts and even accelerates during the combustion. The reaction chain is formed by the disintegration and recombination of the molecules that make up a flammable material with the oxygen of the atmosphere. The investigation of this concept has led to the discovery of many extinguishing agents that are more effective than those that managed to open the triangle. Due to this discovery, the fire triangle can be turned into a three-dimensional pyramid known as the "fire tetrahedron" (Hasofer, Beck, & Bennetts, 2006) (Fig. 1). This difference in the literature does not eliminate all the old procedures that can be used in preventing fires, but it provides additional tools with which fires can be prevented or extinguished. This difference in the literature does not eliminate all old procedures that can be used to prevent fires, but it provides additional tools to prevent or extinguish fires. When disasters that occurred in buildings throughout history are examined, fire has always been one of the greatest threats to life (Hurley, et al., 2016). In the oldest times, fires occurred in the natural environment of forests and meadows, while today the greatest fire risk in the historical fabric is fires that occur on flammable materials in the built environment. The most important reason for this can be shown as the lack of architectural/engineering services required for fire safety of historical buildings as they are today and the lack of sufficient information about fire by users (the formation of fires and what can be done to prevent it, as explained above).

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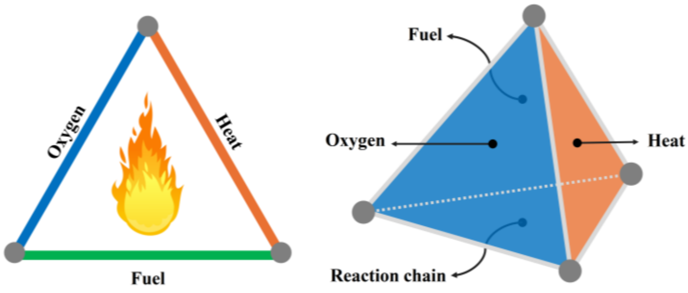

Fig. 1. Fire triangle and fire tetrahedron (Adapted from Hasofer et al. (2006))

In the first settlements built throughout history, buildings were generally small and single-story. This provided the residents with the opportunity to escape to a safe place. Since they were simple structures, lost property could be replaced relatively quickly. As civilizations became more organized and complex, settlements became larger. Buildings began to have upper floors, fires broke out, especially from the appliances used in kitchens and living rooms, and candles and gas lamps used for lighting purposes added to the fire risks, increasing the overall fire risk of the building. Throughout history, disasters such as the Great Fire of London in 1666 have caused great loss of property and life in such communities (Kıdd, 1995).

The best response to such disasters has been to learn from them. Some of the lessons learned over time include; development of building codes, consideration of compartment size (in terms of volume) in terms of fire resistance, awareness of the need for a consistent fire precaution package, importance of occupant response to fire and human behavior in a fire, etc. However, increased fire precautions in buildings have not ensured safety and fire disasters continue to occur even in seemingly safe buildings. Therefore, the way to deal with the stochastic (or random) nature of fire is probabilistic fire risk assessment (Ramachandran & Charters, 2011).

Historical buildings are vulnerable to fire due to the limited architectural/engineering services they receive and the inadequacy of the materials used in terms of fire resistance when the year of construction and the conditions of that year are taken into account. In this sense, conducting fire risk assessment on historical buildings is very important in transferring these buildings, which have symbolic value for society and are an important element of cultural sustainability, to future generations. The study focused on Fire Risk Assessment (FRA) methods accepted in the literature due to the sensitivity of historical buildings to fire.

1.1. Methodology

Within the scope of the study, the general classifications of FRA methods in the literature, the reasons for the emergence of these classifications and FRA methods specific to historical structures were investigated. As a result of these studies, the selected FRA methods were analyzed over the determined analysis headings. As a result of these analyses, evaluations and some inferences were made specifically for historical structures (Fig. 2).

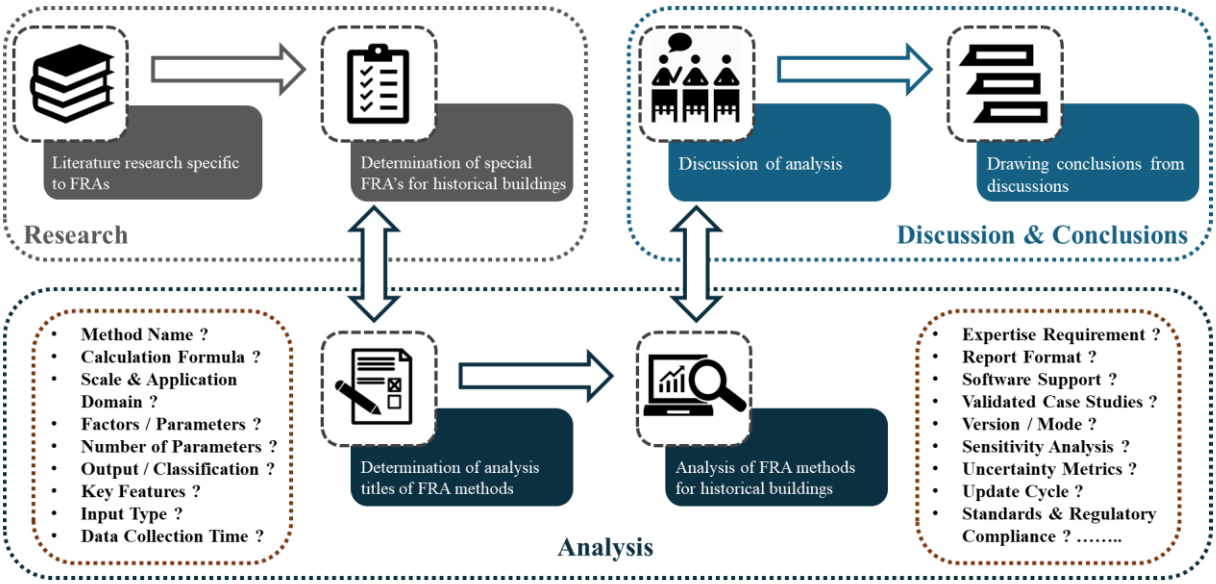

Fig. 2. Schematic description of the methodology of the study

2. Fire Risk Assessment (FRA) methods

Fire Risk Assessment (FRA) methods are a preventive tool for architects and engineers to evaluate fire risk, its possible consequences and the necessary safety measures. Risk prevention methods are the most practical tools in minimizing the consequences of fire, as they include some unpredictable factors such as human behavior and the response time of rescue services. Guerrazzi (2023)'s SFPE Fire Risk Assessment Guide defines Risk Assessment as "the process of generating information about acceptable risk levels and/or risk levels for an individual, group, society or the environment." As can be understood from their definitions, FRAs have a complex structure due to the fact that different factors serve a common purpose together. For this reason, there are many different classifications in the literature. These classifications are summarized below.

2.1. Classification of FRA methods

According to different sources, FRA methods can be classified in more than one way depending on the criteria chosen (Fig. 3). These classifications are not mutually exclusive, but they form a complex network where the same method can belong to several categories according to the criteria chosen (Iglesias, 2018). Not all methods can be classified into one of the above categories, and all categories are interrelated. In addition, sometimes the name of the category is a method itself (as in the case of checklists or indexing methods).

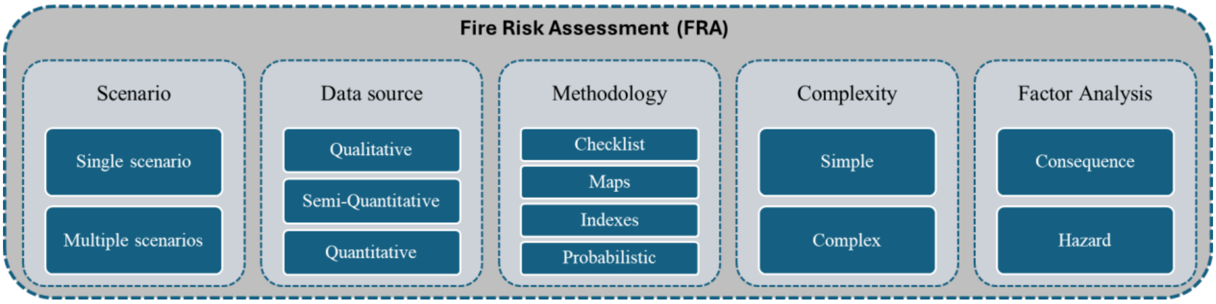

Fig. 3. Different types of classification of fire risk assessment methods (Adapted from Iglesias (2018)).

Among all the methods mentioned above, the most preferred classification is the one made through “Data source”. Within this classification, there are various different methods under the headings “Qualitative, Semi-Quantitative and Quantitative” (Fig. 4).

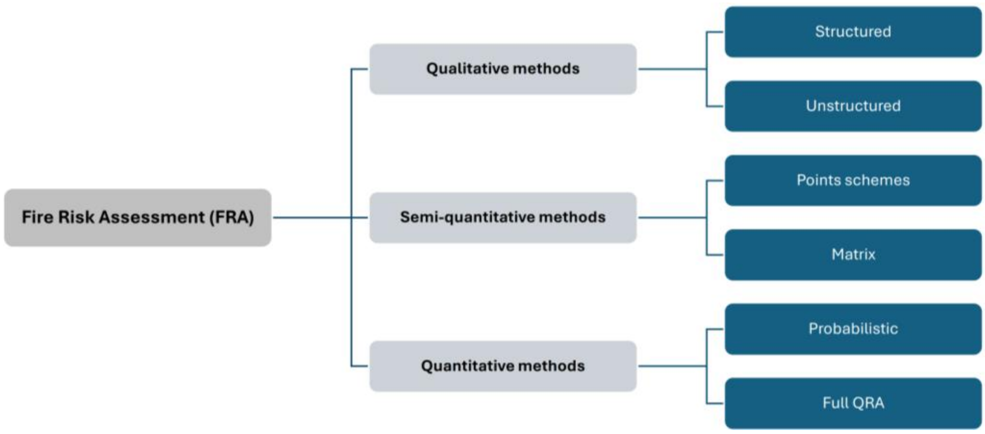

Fig. 4. Widely preferred classification of FRA methods (Adapted from Ramachandran & Charters (2011)).

Qualitative fire risk assessment is based on a subjective judgment not only of the probability of a fire hazard or fire scenario occurring, but also of the outcome of such a fire hazard or fire scenario. Qualitative fire risk assessment is often used to obtain a rapid assessment of potential fire risks in a building and to consider various fire protection measures to minimise these risks (Yung, 2008). Qualitative methods are based on identifying the factors that affect risk. These factors can be factors that affect the level of danger, such as the level of fire precautions aimed at reducing the hazard, such as flammable materials or fire detection. All of these factors are assessed against a set of benchmark values and a judgement is made as to whether the factor is higher, lower or about the same as the benchmark. All factors are then examined to assess how the assessed area compares to the benchmark values. Assessments under fire regulations for existing buildings usually fall into this category (Ramachandran & Charters, 2011).

Semi-Quantitative fire risk assessment methods give a numerical value to the risk level; however, this numerical value does not represent an exact risk value (Ramachandran & Charters, 2011).

The term quantitative fire risk assessment refers to an assessment that includes numerical quantities not only of the probability of a fire hazard or fire scenario occurring, but also of the consequences of that fire hazard or fire scenario. The numerical values of probability and consequence are multiplied to give each fire scenario a numerical fire risk value. By adding the risk values from all possible fire scenarios together, we can obtain an overall fire risk value. The overall fire risk value can be used to make comparisons with alternative or code-compliant fire safety designs (Yung, 2008).

3. Historical buildings and FRA

Historical buildings around the world are exempt from local and/or international building codes, relying on the experience of designated authorities to determine what is safe or what is an acceptable equivalent to a specific code requirement. In this sense, historic buildings suffer under codes that either completely ignore historical significance or impose strict safety requirements with minimal regard for culturally significant areas and materials. As a result, the historic character of a building can be damaged by the strict application of fire safety codes. At the same time, the current international perspective on fire safety objectives includes, in particular, the protection and preservation of life, property, mission, environment and cultural heritage (Watts Jr. & Kaplan, 2001).

Historic buildings present unique challenges for fire protection. Unlike most public and commercial buildings, a historic building exists as a work of architectural or historical significance or as a visual record. If the building is demolished, this function is eliminated. Creative solutions must be developed that meet fire and life safety objectives without compromising the historic building’s historical or architectural significance. However, no statistics are available to determine the fire vulnerability of historic buildings (Watts Jr., 1996).

It is not known exactly how much of the world's cultural heritage has been lost to fire. Fire loss data is collected only on factors related to the cause and origin of the fire. There is no fire loss data by historical significance or building age. The vulnerability of historic buildings to loss or damage from fire increases with each major fire that destroys a historic building and its contents. Historic buildings are not buildings that can be replaced, but rather irreplaceable artifacts whose value cannot be recovered through insurance payments (Watts Jr. & Kaplan, 2001).

The use of existing and abandoned historical buildings by changing their functions or preserving their existing functions is quite common today. In the face of this situation, some administrations have attempted to prepare regulations specific to these historical buildings. However, although some of the emerging approaches are more progressive than others, most of them contain incommensurable terms such as "minimum", "acceptable", "sufficient" and "reasonable". This uncertainty puts the designer, the property owner or user and the inspecting institution in a difficult position (Watts Jr. & Kaplan, 2001). As can be understood from all these uncertainties, it is very difficult to determine the behavior of historical buildings during fire through regulations.

Therefore, it is necessary to develop methods to assess the fire safety of built cultural heritage assets, taking into account their specific characteristics and focusing on the protection of heritage values. However, for most countries, conducting multi-hazard risk analysis for a large number of cultural heritage assets often requires unachievable efforts and budgets. Therefore, assessing risks for a large number of assets with limited resources is only possible when based on simple methodologies (Romão, Paupério, & Pereira, 2016). The development of risk assessment methods for historic buildings should also take into account the possibility of their application to a large number of historic buildings (e.g. in a region or across the country) without requiring excessive manpower and economic resources. Furthermore, given that historic buildings with different characteristics are likely to have different fire vulnerability factors, the specified methods should be able to account for these differences. Therefore, these methods need to be simple, yet reliable and versatile.

3.1. FRA methods for historical buildings

Fire assessment of historical structures can be applied at the scale of a single structure or at the scale of urban and/or rural settlements. Historical structures are generally located within old settlement areas and many old and new settlements are observed within these areas. In this sense, it is not possible to evaluate them independently from their surroundings in terms of risk assessment. In this sense, the complex structures of qualitative methods can be partly difficult to apply in large areas. Indicator-based methods (also called risk indexing methods) have been widely preferred in the literature in order to provide a simple and reliable way to determine the fire risk level of existing structures over large areas. Fire risk indexing systems are intuitive models of fire safety. They constitute the processes of analyzing and scoring hazards and other system features to produce a fast and simple estimate of relative fire risk. They are also known as rating tables, score schemes, ranking, numerical rating and scoring. Using professional judgment and past experience, fire risk indexing assigns values to selected variables representing both positive and negative fire safety features. The selected variables and assigned values are then processed through a combination of arithmetic functions to arrive at a single value, which is then compared to other similar assessments or a standard (Watts, 2016).

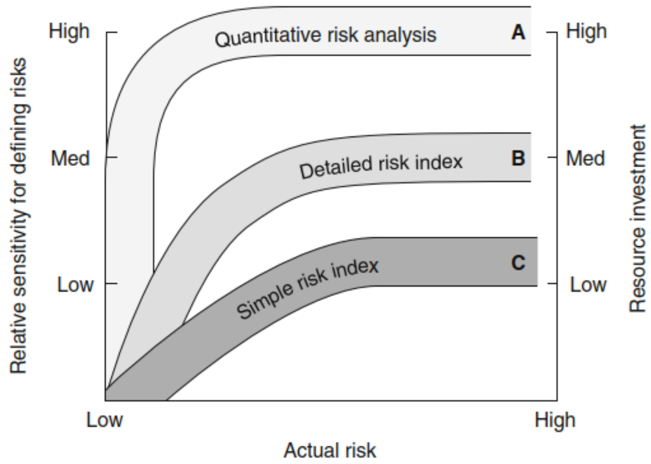

Fig. 5. Relative sensitivity for defining actual risk (Rosenblum & Lapp, 1989; Watts, 2016)).

Indexing methods are shown under the titles of "Semi-Quantitative methods" according to some sources and "Quantitative methods" according to some sources. This classification varies according to how FRAs are classified. However, the simplest explanation of this classification can be given through the graphic in Fig. 5 below. Even if the details of indexing methods are examined, they cannot provide results as sensitive as quantitative risk methods. For this reason, it is more possible to associate indexing methods with semi-quantitative methods (since they give a numerical value to the risk level, but this numerical value does not represent a definite risk value).

Within the scope of the study, the methods used in FRA research of historical structures in the literature are given below. As mentioned above, these methods are evaluated as "Semi-Quantitative" in some sources and "Quantitative" in some sources. The sources in question are presented under the titles of method name, year, place of origin, target structure (structure class) based on the study conducted by Salazar et al. (2021).

Table 1. FRA methods for historical buildings (Adapted from Salazar et al. (2021)).

Method / Year	**Origin**	**Target constructions**
GRETENER /1961-1968	Switzerland	Industrial buildings, but also used in other buildings
PURT – EURALARM /1972	Serbia	New and existing buildings
TRVB /1975-1987	Austria	New and existing buildings
ERIC /1977	France	Industrial and office buildings, dwellings
FSES /1978	USA	New and existing buildings
BOCA /1990-1996	USA	Existing buildings
ILHR/1995	USA	Historic buildings except nursing homes, hospitals and residential facilities
ARICA /1997-2000/2010	Portugal	Old urban centres
MESERI /1998	Spain	Low risk industrial buildings, but also used in other buildings
HFRI /1998-2001	UK	Historic house museums
FRIM-MAB /2000	Sweden	Multi-storey apartment buildings
SEPC /2002	Wales	Churches
FRACM /2002	Canada	Collections in museums considering the building characteristics

Table 1. continued

RAGER /2002	France	Movable objects in churches considering the building characteristics
FRAME / 2008	Belgium	New and existing buildings
MARIU /2011	Portugal	Existing buildings in old urban centres for fire risk mapping
FETAM /2013	Taiwan	Monuments and historic buildings
FRIM-HB /2014	Italy	Historic buildings
CHICHORRO /2016	Portugal	Existing buildings

When the risk definitions of the methods listed above are examined in detail, it is seen that some methods have similar formulations. This shows that the methods are developed over each other. In this sense, for example, although the FRIM-MAB and FRIM-HB methods are almost completely similar, the change in formulation is seen in the case of historical buildings. Due to such similarities, all these methods are grouped under three main headings according to Salazar et al. (2021):

a) Methods developed for ordinary structures and applied to cultural heritage assets or taking into account factors/criteria that are important for cultural heritage assets.
b) Methods developed for historical or older structures based on existing methodologies (Methods colored gray in Table 1).
c) Methods developed specifically for cultural heritage and historical structures.

The methods included in category "a" are; GRETENER, EUROALARM-PURT, TRVB, ERIC, FSES, BOCA, MESERI, FRIM-MAB and FRAME, respectively.

The methods included in category "b" are; ARICA, MARIU, CHICHORRO, ILHR and FRIM-HB, respectively. While ARICA, MARIU and CHICHORRO focus on old city centers, ILHR and FRIM-HB are created specifically for individual buildings. In addition, HFRI is partially accepted in this category because it focuses on historical museums.

The methods included in category "c" are; SEPC, FETAM, FRACM and RAGER, respectively. While SEPC and FETAM focus on historical structures, FRACM and RAGER are more focused on portable cultural assets.

4. Analysis of FRA methods for historical buildings

In light of the information provided above; the target structures for fire risk assessment in historical buildings are the "b" category, which is determined as the scope of the study. The study focused on the "b" category because the main target of the "a" category is not directly historical buildings, and the "c" category focuses on more symbolic structures and portable cultural assets compared to other historical buildings.

The methods in this category will first be analyzed based on the items specified in heading 4.1 below, and various inferences will be made from this analysis data..

4.1. Determination of analysis titles of FRA methods

When the methods in Table 1 are examined, different formulations and risk definitions are seen in each of them. This situation is due to the complexity of the general operation of the risk analysis, where different factors can coexist.

The ideal theoretical environment for conducting a risk analysis requires the probabilistic quantification of hazard, vulnerability and resilience. Both sufficient/reliable data and adequate analytical/numerical procedures are required to create probabilistic representations of these components. However, in many cases, especially in the risk analysis of cultural heritage assets, defining these components in a reliable probabilistic context becomes very complex (Romão, Paupério, & Pereira, 2016).

Probabilistic representation of risk is generally carried out on data obtained from past events. Probabilistic risk definition can be made for natural events such as earthquakes, floods, landslides or volcanic movements (Romão, Paupério, & Pereira, 2016). However, it is quite difficult and complicated to make a clear definition on fires, especially in historical buildings, due to the lack of data definition (Kincaid, 2022). When working on cultural heritage assets, the multidimensional nature of the asset's value and the complexity of its assessment are major conceptual hurdles.

To create a comprehensive risk assessment procedure and implement a framework within which the results can be regularly updated over time, the following key issues should be integrated:

a) Reliable and sufficient data for the development of appropriate hazard models.
b) Sufficient and reliable data regarding the assets at risk.

c) Appropriate procedures for modeling vulnerability.
d) Adequate models to predict the multidimensional consequences of the hazardous event.
e) Having sufficient human, time and economic resources(Romão, Paupério, & Pereira, 2016).

In the context of a risk assessment procedure for cultural heritage assets, the most difficult issue to address, regardless of the hazard in question, has been "d". Furthermore, in order to successfully address "a, b and c", issue "e" must be provided as a priority. All these fundamental issues will define the scope and comprehensiveness of the risk analysis and will be the basis for the successful regular updating and monitoring of the risk assessment results over time (Romão, Paupério, & Pereira, 2016). For this reason, it is important to have a simple methodology that can be used to determine risk reduction priorities or to identify assets that require more detailed data, especially in methods where many structures are included in the analysis and located in old settlements such as historical buildings.

In this context, the following analysis headings were determined to discuss the above outlined characteristics through the selected FRA methods (ARICA, MARIU, CHICHORRO, ILHR, HFRI and FRIM-HB):

Scale & Application Domain, Factors / Parameters, Number of Parameters, Output / Classification, Key Features, Input Type, Data Collection Time, Expertise Requirement, Report Format, Software Support, Validated Case Studies, Version / Mode, Sensitivity Analysis, Uncertainty Metrics, Update Cycle, Standards & Regulatory Compliance, Advantages and Disadvantages.

4.2. Analysis of FRA methods for historical buildings

For the comparative analysis of FRA methods, the headings determined above will be applied. First of all, the general definition of ARICA, MARIU, CHICHORRO, ILHR, HFRI and FRIM-HB methods and the sources used are given in Table 2 below. Table 3 includes a detailed comparison of the FRA methods with previously determined analysis headings.

Table 2. Calculation formulas for FRA methods

Method	Calculation Formula	Reference
ARICA	$FR_I = \frac{(1.20 \times SF_I + 1.10 \times SF_P + SF_E + SF_C)/4}{FR_R}$ *FR_I = fire risk assessment* *SF_I = ignition phase factor* *SF_P = propagation phase factor* *SF_E = evacuation phase factor* *SF_C = fire combat factor* *FR_R = reference risk factor*	- (Vicente, Silva, Varum, & Costa, 2010), - (Granda & Ferreira, 2019), - (da Mota, 2014), - (Almeida, 2013), - (Muculo, 2013), - (Santos, et al., 2011).
MARIU	$RL = E\sum_{i=1}^{11} WC_i \cdot SL_i$ *RL = risk level* *E = equalisation factor* *WC_i = weight of factor i* *SL_i = severity factor i*	- (Lopes, Coelho, & Rodrigues, 2011), - (Lopes, Coelho, & Rodrigues, 2012).
CHICHORRO	$RI = P \times G$ *RI = fire risk* *P = probability of fire ocurrence* *G = severity of fire consequences*	- (Gonçalves & Correia, 2016), - (Soares, 2021), - (Coutinho, 2017).
ILHR	$S = \sum_{i=1}^{17} w_i r_i$ *S = evaluation score* *w_i = weight of factor i* *r_i = normalized rating of factor i*	- (Rasbash, Ramachandran, Kandola, Watts, & Law, 2004), - (Kaplan & Watts, 1999).
HFRI	$(A \times B) = \sum_{i=1}^{11} A_i \times B_i$ *A × B = fire safety score* *A_i = value of factor i* *B_i = weight of factor i*	- (Kaplan & Watts, 1999), - (Watts Jr. & Kaplan, 2001).
FRIM-HB	$RI = 5.00 - S = 5.00 - \sum_{i}^{23} w_i x_i$ *RI = risk index* *S = safety score of the building* *x_i = score of factor i* *w_i = weight of factor i*	- (Arborea, Mossa, & Cucurachi, 2015).

Table 3. Comparative analysis of FRA methods for historical buildings

Feature	ARICA	MARIU	CHICHORRO	ILHR	HFRI	FRIM-HB
Scale & Application Domain	Historic urban fabric: streets, blocks, individual buildings	Urban building stock; mid-level technical expertise	Building-level, general purpose	Commercial historic buildings ≤1,115 m²	Historic house museums	Historic buildings; integrated with Carta del Rischio
Factors / Parameters	4 global (FGII, FGDPI, FGEE, FGCI); ~15 partial	11 SL × CP; E coefficient	4 global: POI (12), CTI (3), DPI (5), ESCI (7)	17 parameters (A × B)	11 parameters; w_i (%), r_i (0–5 Likert)	17 P + 6 N hierarchical
Number of Parameters	≈15	11	27	17	11	23
Output / Classification	Risk >1 → action needed; risk map; rapid screening	GR ∈ [38–1200]; 5 risk levels	Grades A++…F ("Very Low"–"Immediate")	Score; additional measures per code	Grades A++…F ("Very Low"–"Immediate Intervention")	RI [0–5]; lower RI = higher safety
Key Features	GIS integration; simplified & detailed versions	Rapid matrix; geographic mapping	Holistic optimization; simplified input mode	Heritage fabric conservation; flexible scoring	Performance-based; collection preservation focus	Policy & strategy oriented; heritage preservation
Input Type	Quantitative	Quantitative	Quantitative	Quantitative/Qualitative	Quantitative	Quantitative
Data Collection Time	Medium (1–2 days)	Low–Medium (1 day)	High (2+ days)	Medium (1–2 days)	Medium (1 day)	Medium (1–2 days)
Expertise Requirement	High	Medium	High	Medium	Medium	Medium–High
Report Format	Risk maps & tables	Matrix tables	Summary tables & score charts	Compliance reports	Score tables	Risk report format
Software Support	ArcGIS, QGIS integration	Microsoft Excel; ArcGIS; QGIS	Custom scripts (Python, R)	None	Microsoft Excel	Carta del Rischio GIS; ArcGIS
Validated Case Studies	Paranhos, Seixal, Viseu	City-wide applications	Amarante pilot	Wisconsin historic buildings	House museum pilot	Rome public office
Version / Mode	Simplified version available	None	Simplified mode available	None	None	None
Sensitivity Analysis	Available	No	Available (parameter ranges)	No	No	No
Uncertainty Metrics	None	None	Yes	None	None	None
Update Cycle	Periodic reviews	Periodic updates	Project-based	Code revision-based	Regular form updates	Continuous updates
Standards & Regulatory Compliance	Compliant with local codes	Aligned with general risk standards	Independent methodology	Direct code compliance	Museum standards	Italian risk mapping standards
Advantages	Detailed analysis; geographic integration	Fast; user-friendly	Holistic & optimizable	Heritage focus	Collection preservation	Integration; policy focus
Disadvantages	High expertise; time-consuming	Limited risk detail	Complex; tool dependencies	Limited to small buildings	Narrow scope	Complex hierarchy

5. Discussion

The differences between the scope, purpose and application features of ARICA, MARIU, CHICHORRO, ILHR, HFRI and FRIM-HB methods reveal the strengths and weaknesses of each method in terms of target scale, data requirement, interpretation style and legislative compliance.

When we look at the scale and purpose compatibility, ARICA and MARIU are approaches designed to perform risk mapping at the urban fabric level, providing rapid scanning opportunities at the block and street scale. While ARICA provides detailed spatial analysis with a data collection period of 1–2 days thanks to the integration with geographic information systems; MARIU offers a practical solution using a simple Excel-based matrix completed in just one day. In contrast, CHICHORRO and FRIM-HB simultaneously evaluate both the probability of fire occurrence and the severity of its consequences with building-based holistic optimization principles; however, comprehensive parameter sets and special automation scripts increase the application time and the level of expertise required.

In terms of speed and user-friendliness, MARIU has the highest ease of use and speed advantage among all methods, while ARICA balances the advantages of moderate complexity and rapid geographic analysis. While CHICHORRO and FRIM-HB require detailed modeling, ILHR and HFRI offer direct regulation or form-based scoring, providing relatively less automation in the field, but a more limited scale and scope of objectives

In terms of Expertise Requirement and Automation, ARICA, MARIU and FRIM-HB offer integration with common geographic or spreadsheet software (ArcGIS, QGIS, Excel) to support data processing and mapping automation; whereas CHICHORRO's Python/R scripts provide in-depth analysis but require initial development. ILHR and HFRI operate via manual form updates and score tables, thus offering limited automation possibilities but offering the advantage of direct compliance with legislation or museum standards.

In terms of uncertainty and sensitivity analysis, ARICA and CHICHORRO allow sensitivity control with parameter ranges against the variability of conditions. Since most of the other methods do not include uncertainty metrics or formal sensitivity analyses, additional Monte Carlo or probabilistic calculations can be suggested to increase the reliability of these models.

Regarding standard and regulatory compliance, ILHR and HFRI fully serve the relevant code and museum standards, while ARICA and MARIU provide a more flexible compliance, while FRIM-HB is directly integrated into the Italian "Carta del Rischio" framework.

Consequently, considering the scale, time constraints, data access possibilities and regulatory requirements required by the institution or project:

- MARIU for rapid, city-wide screening,
- ARICA for geographically detailed analysis,
- CHICHORRO or FRIM-HB for comprehensive optimization at the building scale,
- ILHR or HFRI should be preferred for situations requiring official approval and regulatory compliance.

6. Conclusions

In this study, six different fire risk assessment methods ARICA, MARIU, CHICHORRO, ILHR, HFRI and FRIM-HB were compared in terms of scale, data requirement, automation level and regulatory compliance. Among the examined methods, there is a clear distinction between rapid urban scale scanning (MARIU), block and street level analysis supported by geographic information systems (ARICA), building-based holistic optimization (CHICHORRO, FRIM-HB) and regulation-based scoring (ILHR, HFRI). This differentiation reveals that each method requires a multi-dimensional set of selection criteria, from the number of parameters to uncertainty and sensitivity analysis, from software integration to field implementation time. Therefore, not only speed or detail but also automation capability, level of expertise and regulatory compliance should be equally taken into consideration in risk assessment processes.

A holistic and sustainable fire risk management in historical building groups can only be achieved by consistently matching the technical capacity of the selected method with the application context. In this context; the size and depth of coverage of the parameter set, the level of automation and the presence of uncertainty analysis tools; whether the risk model will be applied at the city scale or on a single structure basis; data access, data quality and timeliness; and the harmonious construction of stakeholder participation dynamics (interaction mechanisms between fire departments, conservation experts, local governments and property owners) are of critical importance. In the selection of the method, not only the quantity and quality of the available data, but also how the model outputs will be interpreted by decision makers and the ways of integration into response planning should be taken into account. Furthermore, the systematic inclusion of continuous monitoring and update cycles in the methodology; for example, automatically updating the findings obtained through periodic field inspections via digital platforms, will both maintain the real-time validity of risk scores and allow for flexible revision of long-term response strategies. This approach will also support different scenario analyses, ensuring that resource allocation, emergency training and policy development are carried out within an integrated framework, thus paving the way for the dynamic improvement of fire safety standards specific to the historical texture.

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Revitalizing cultural heritage: The transformative power of circular adaptive reuse in Istanbul ferry boat stations

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Abstract. Adaptive Reuse (AR) of cultural heritage is a systemic process playing a critical role in the debate towards a more sustainable future in cities. AR stands as a crucial strategy for preserving heritage values while adapting them for future uses. However, while repurposing built heritage can be considered as a reliable strategy for reaching a better social and economic future in cities, the cultural values of heritage assets can be underscored. This paper focuses on the importance of the circular AR of cultural heritage suggesting that assigning new functions to the historical buildings contributes to the circularity-based sustainability in cities. The following research aims to reveal the transformative power of circular AR of built heritage adopting the revitalization of ferry boat stations in Istanbul as a case study. From this aim arises one main objective, i.e., revealing the social, economic and cultural value of circularity-based AR of historical ferry boat stations. Therefore, ferry boat stations in Istanbul transcend the fact of being just transportation hubs; they are a witness to the city's rich cultural heritage. Preserving their authenticity, integrity and significance while adapting them to present needs is fundamental for maintaining the Bosphorus's legacy of linking various regions with unique heritage. Examining the broader implications of circular economy (CE)-based cultural regeneration, the findings showed that circular AR have a role to play in both the socio-economic and cultural revitalization, namely the heritage tourism promotion, the local business enhancement, and the local civic pride conservation. Ultimately, this paper suggests that Istanbul's ferry boat stations play a role model for other cities aiming at setting a balance between heritage conservation and the demands of the circular city development.

Keywords: Circular adaptive reuse; Revitalization; Built heritage; Ferry stations

1. Introduction

Many definitions are given to the circular economy (CE) concept resulting in some confusions. Although, it emerged as an industrial ecology concept and was applied as a symbiosis tool for managing wastes, the popularity of CE spread out to include many other disciplines (Dąbrowski, M., Williams, J., van den Berghe, K., & van Bueren, E. 2024). Therefore, in the current concern for more livable cities, CE holds a premium role by enhancing both environmental quality and economic prosperity, while putting forward social equity for future generations (Dąbrowski, et al., 2024).

Since construction and building sector are topping in the nonrenewable energy conception, they started to intensively make use of the CE's regenerative power (Mariarosaria, et al., 2023). According to the 2020 European Commission's (EC) report on Energy efficiency in building, the building sector accounts for 36% of global greenhouse gas emissions (EC, 2020, February 17). Thus, to prevent the resultant current resource depletion and environmental impact, and to reach the EU's 2050 aim for 0 gas emission, the CE principles were applied to the building sector including built heritage.

Therefore, the contribution of CE application in the heritage conservation process is evident mostly from its role in AR projects (Gravagnuolo et al. 2021 a, b; ICLEI, 2020). Consequently, in the ongoing debate around achieving a more sustainable future for cities, cultural heritage became increasingly recognized as both an active driver and a viable accelerator. Being both an economic and a cultural asset, cultural heritage contributes to economic enhancement, plays a role in upgrading urban quality and environmental compliance (Buglione, F. *et al.* 2025). Thus, relying on the transformative power of circularity-based cultural heritage AR, it became possible to increase the lifespan of buildings, reduce waste, prevent resources depletion and promote innovative design strategies for heritage buildings while preserving their cultural value (Chiacchiera & Mondaini, 2023; Nasrullah, 2024). However, while circular AR is playing a significant role in building the way to more sustainable futures, it

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still reflects challenges particularly in balancing preservation prerequisites with modernization needs. Its challenges lie also in managing regulatory frameworks that enhance cultural heritage protection.

The present study discusses circularity-based heritage revitalization initiatives, questioning the transformative power of adaptive reuse of cultural heritage (ARCH) as a driver for CE implementation in heritage conservation strategies. In this perspective, the rich shore-built heritage of Istanbul city has been taken as an example. Based on onsite observation and the theoretical model building method, the following study aimed at revealing the social, economic and cultural value of circularity-based AR of historical ferry boat stations.

The following section illustrates the conceptual framework defined from the literature review and defines the main indicators for circular AR of heritage buildings regardless of the heritage context.

2. Theoretical framework: Adaptive reuse strategies for heritage buildings

As opined by Williams (2019), despite periodic technological upgrades, core infrastructure systems in many countries have remained fundamentally unchanged for decades making built heritage needing rehabilitation or replacement. Building on the potential of ARCH to activate circularity-based sustainability in cities/regions, and the crucial role AR can play in extending the lifespan of heritage buildings, the following section outlines key aspects of the relationship between ARCH and circularity-based sustainability. In the present study, empirical research based on the 'theoretical model building' (Onwuegbuzie, et al., 2012) has been applied to select, synthesize, and systematize the indicators for the circular ARCH.

2.1. Adaptive reuse of cultural heritage and circularity-based sustainability

ARCH plays a fundamental role in promoting circularity-based sustainability by revitalizing underused or discarded sites while preserving cultural identity. This approach not only improves urban resilience but also nurtures social cohesion and economic enhancement (Gravagnuolo et al., 2021).

Several studies call attention to the connectedness between the sustainable CE concept and the heritage sector (Girard, 2020). Yet, while the input of CE implementation in the heritage conservation process is definite from its role in AR projects (Gravagnuolo et al. 2021; ICLEI, 2020), few studies have examined it from a more comprehensive viewpoint. Girard and Nocca (2019) reviewed the possibility of implementing the CE at an urban scale by focusing on a cultural landscape-based approach assuming that there are interdependence relations between specific landscapes and CE/city models. Hence, in the circular approach, resources are re-used, recovered, regenerated, and shared, extending use values. Among resources, CH that has historical, artistic, and cultural values can play a significant role in the implementation of the "circular city", oriented towards implementing the "human-centered city" (Christian, 2020).

Therefore, according to Bandarin and Van Oers (2012), 'Circular City' initiatives are appropriate for ARCH because the cultural uniqueness of cities is related to features of the urban landscape including buildings (Bandarin and Van Oers 2012). It is also believed that the spatial aspect of CE for implementing the circular city approach is ARCH (Girard, 2020). Within this framework ARCH has the potential to activate the different factors of circularity-based sustainability. ARCH is conceptualized as a strategic approach to advancing a more sustainable, resilient, inclusive, and aesthetically meaningful future (Girard & Gravagnuolo, 2025: 16). As illustrated in Table 1, ARCH encompasses an overlap between the social, economic, cultural, and environmental considerations.

The socio-cultural aspect of AR projects lies in its potential to enhance community engagement (Gravagnuolo et al., 2021). AR increasingly emphasizes putting forward the community's well-being by enhancing social value (Padilla-Rivera, et al., 2020; Lundgren, 2023; Andreucci & Karagözler, 2025). Involving local stakeholders in decision-making processes enhances civic responsibility and strengthens community bonds, as demonstrated in the example of Salerno, Italy (Gravagnuolo et al., 2021). In another research, Maha Shree, et.al, (2025) elucidated the diverse methodologies employed in adapting historical structures for contemporary uses while safeguarding their intrinsic cultural value.

Table 1. Indicators for the adaptive reuse of cultural heritage (Source: the author)

Embedded indicators	Sub-indicators
Socio-economic indicators	Heritage tourism promotion, community revitalization (Maha Shree, et.al, 2025; Padilla-Rivera, et al., 2020; Lundgren, 2023; Andreucci & Karagözler, 2025)
Economic indicators	Investment and Funding, job creation, tourism-based investments (Gravagnuolo et al., 2021; Rudan, 2023)
Social-cultural indicators	Community well-being, cultural identity, civic pride enhancement, community engagement (Gravagnuolo et al., 2021)
Environmental indicators	Minimizing waste and reducing the consumption of new resources (Foster, 2020; Bosone et al., 2021).

The study helped investigate the socio-economic advantages of AR initiatives that are including, but not limited to heritage tourism promotion, community revitalization, and sustainable development. Moreover, the same research addressed the ethical considerations and conservation principles guiding AR practices to ensure that sustainable heritage management, be the potential actor to preserve authenticity, integrity and significance of cultural heritage assets. It, however, underscores the imperative of AR as a vibrant tool for safeguarding cultural heritage for future generations.

Economically wise, revitalizing cultural heritage sites through AR practices has the potential to stimulate local economies through job creation and increased tourism, as seen in several tourism destinations (Rudan, 2023). However, this contribution remains questioned especially when it comes to repurposing existing buildings for retail use (Maha Shree, et.al, 2025). Therefore, from this perspective, managing old buildings is a difficult undertaking. Retail-reuse projects typically involve many stakeholders having different interests, i.e., heritage conservation actors like governmental agencies that focus mostly on preserving the historical significance of heritage buildings, and investors who opt for economic profit.

Environmentally wise, applied materials and methods for the conservation and restoration of cultural heritage have the potential to be energy consuming, not environmentally friendly and sometimes even damaging for the health of executors. Therefore, many of the applied materials and technics prove to be neither durable nor sustainable, often leading to recurring and expensive heritage solutions (Angrisano et al., 2025: 117-118). However, aligning with CE principles ARCH has the potential to help minimize waste and reduce the consumption of new resources when revitalizing degraded heritage buildings (Foster, 2020; Bosone et al., 2021). The transformative power of circularity-based ARCH does not encompass the environmental aspect only. Inscribed in a holistic urban governance approach, circular ARCH has the gage to stimulate growth, sustainable development, social regeneration, welfare, jobs, income and livability cities/regions (Tira & Türkoğlu, 2023; Fusco Girard & Gravagnuolo, 2025).

2.2. The transformative power of the circular adaptive reuse of cultural heritage

Each city has unique characteristics and its own social and economic structure. Thus, to implement the circularity approach to its different assets, each city needs to assess the appropriate starting point. Based on the Sustainable Development Goals (SDGs) and the EU's 2050 target of 0% emissions, the EU launched the Green Deal strategy (EC, 2019) based on CE principles. The initiative showed that the circular concept can go beyond the economic circle and that cities can also adopt it to reach a long-lasting sustainable future (EC, December 11, 2019).

Putting culture at the heart of the Green Deal was meant to adopt cultural heritage as the starting point to reach Europe's 2050 goal (EC, 11 December 2019). Historic city regeneration and renewal approaches are seen as an effective entry point for the implementation of a circularity-based sustainable future (Nocca et al. 2021). However, as claimed by Nocca et al. (2021), regardless of the growing interest in CE implementation, the debate around it remains more on a theoretical level. Knowledge about how to implement the circular approach to heritage assets is still confusing.

Pioneers in adopting the circularity approach in ARCH to attend self-sustainability, are the Regeneration and Optimization of Cultural Heritage in Creative and Knowledge Cities (ROCK) (ROCK, 2019) and the Circular Models Leveraging Investments in the Cultural Heritage Adaptive Reuse (CLIC) project (ICLEI, 2020).

These studies are based on the idea that CH is used as a tool to experiment with collaborative models of urban development (Garzillo et al. 2018; ROCK, 2019). Both examples applied CE principles to CH regeneration through AR, achieving environmental, social, cultural, and economic sustainable urban development. Therefore, the objective of the CLIC initiative is to provide strategic guidance to a diverse range of stakeholders—including municipalities, public authorities, financial entities, private sector actors, civil society organizations, and cultural institutions—in the implementation of local development strategies. These strategies are principally based on harnessing the 'transformative potential' of ARCH (Fusco Girard & Gravagnuolo, 2025: 16).

One example of pilot projects led in the ROCK initiative is the case of the historic city of Bologna which is a replicator city of the ROCK project. In this example, the policy of the project is based on coordinating the collaboration between the different urban stakeholders and actors, including the community, for the regeneration of urban heritage.

In this circularity-based ARCH ore focus is given to developing inclusive and accessible public spaces in the city center and the university area of Bologna. This was achieved by enhancing pedestrianization and slow mobility through planning cultural roots, and the green mobility concept. Following a circular policy for ARCH, the historic city of Bologna could also preserve the architectural features that the porticoes are carrying (UrL-1). Therefore, the collaboration between the community and the city for the regeneration of urban commons in Bologna has been evaluated as a good governance model worth sharing with other cities (ROCK, 2020).

The example of ARCH based ROCK principles is Skopje North Macedonia. The chosen ROCK project area in Skopje city is comprised of a protected area of CH of high significance (a city fortress, the Old Bazaar, and many buildings and monuments, a vibrant open-air green market, a residential area, a commercial area, a mixed-use cultural center, four universities and finally several museums in the former Jewish district in Skopje). This multi-functional trait of the historic city contributed to attracting a large number of visitors.

However, the central area witnessed some neglect. Thus, within the ROCK initiative, and based on a collaborative co-planning principle, Skopje municipality tried to focus on the social, economic, and cultural production of space mainly through the introduction of contemporary "crafts" by ICT incubators and the collaborative workspaces for new creative industries. Consequently, the process of the project concluded in transforming the old center of Skopje into a knowledge culture technology-driven hub where heritage-based regeneration and sustainable urban development are playing a crucial role (ROCK, 2020).

Similarly, the historic center of the Netherlands had also gone a circularity-based ARCH. In Eindhoven's role model city, Living Lab applications helped implement a data infrastructure that has the potential to improve the community's quality of life in the demonstration area. The area defined for the ROCK project in Eindhoven, the NRE site, is including industrial heritage buildings, old commercial buildings, homes, and even old trees. A "*collectively supported plan*" has been implemented by the municipality for the repurposing of the former industrial regeneration area, i.e. the center of Brainport Region, Eindhoven. Under the arch of the developed 'Strijp-S' Living Lab, and collaboratively with the community, the end result was defined by the users. This made it more liveable, dynamic, and at the same time industrious than it was in old times (Eindhoven Municipality, 2019).

Assessment of the achieved and ongoing ARCH projects under the arch of the Horizon 2020 funded two projects showed that the circular ARCH boosts investment and funding. However, evaluating the financial viability of AR projects, including initial investments and potential returns, is crucial. Besides its economic viability, circular AR has a role to play in local employment as it contributes to job creation (Bosone et al., 2021).

3. Materials and methods

The methodology applied in this study is based on the review of literature sources, and an onsite discovery of AR cases with reference to historic ferry boat stations. Literature sources include scientific references, and international organization reports selected giving priority to the most recent (years 2019–2025). The sources were selected according to the main topic addressed, focusing on the regenerative role of CE in the ARCH buildings.

Through the analysis of existing literature, key criteria are identified for the circular AR in the revitalization of the existing built heritage. Special focus was given to the AR of historic ferry boat stations since they present greater challenges like the need to preserve authenticity and integrity in cities where ferries play a vital role in the transit system.

3.1. Exploration of the case studies' context: adaptive reuse of ferry boat stations in Istanbul

Located on the crossroad between Asia, Europe, and Africa, Istanbul lies at the heart of a dense movement network holding an international significance in terms of maritime transport. At the same time, Istanbul city carries an influence on the local importance of urban movement patterns and character. The morphological structure of the city's shores and the attachment of the residents to the sea enhance the role of sea-based transportation.

In the 1840s, urban maritime transportation was mainly focused on the Golden Horn. In the following years, ferry routes, expanding towards the Anatolian side, became an important element in the city's historical and social development (Çınar, 2023, March 28). This implies that the increasing importance given to maritime transportation in Istanbul resulted in defining the movement patterns and the urban design interventions of the shores. Therefore, sea rotes transportation in Istanbul dates to 1851, an era where the city was still under the Ottoman ruling system. To facilitate the transport in the city of three lands and three waters, the "beneficial company", *Şirket-i Hayriye* was established. The purpose was to respond to the growing transportation needs between Istanbul and the Bosphorus in the mid-19th century and to get by the unsafety of traditional methods that could no longer respond to the needs in terms of comfort and capacity (Şehirhatlari.istanbul, n.d). The launching of the ferry lines accelerated the incorporation of the Bosporus to the city's functional organization making the maritime transportation emerge as the defining figure and be the visionary of Istanbul's skyline.

Currently, sea routes in Istanbul are managed by three different companies, i.e. Dentur, Turyol and Şehir hatları. The ferry piers are distributed along the scenic coastlines of the Bosphorus and the Golden Horn (Fig. 1).

Istanbul ferry boat stations play a crucial role in valorizing the city's rich cultural heritage. Preserving their authenticity, integrity and significance while adapting them to present needs is fundamental for maintaining the Bosphorus's legacy of linking various regions with unique heritage. Currently, some of the ferry stations in Istanbul have additional functions, including cafes, libraries, and sightseeing points alongside their transportation functions, contributing to the reinforcement of social interaction (Yasar & Heinz, 2024).

Several examples of historical ferry boat stations went through AR interventions in Istanbul. A few of them were chosen as case studies for this research. The criteria for the choice of cases are mainly based on the accessibility, the physical condition of the current heritage building, current function of the ferry boat station, the scale of possible degradation after a new function is added to the building, the contribution of the added functions to the local business enhancement, and the involvement in the conservation of the local civic pride.

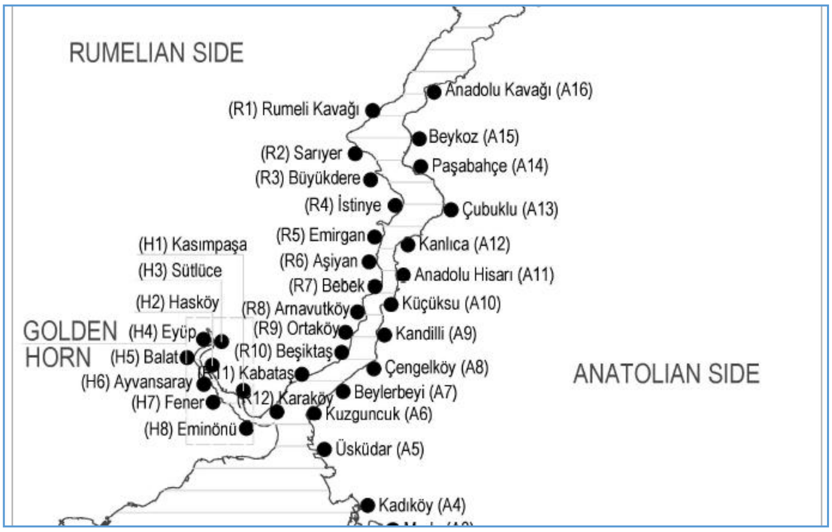

Fig. 1. City line map (Source: Yasar & Heinz, 2024)

The onsite observations were mainly based on the discovery of the architectural features and the building typologies of post-revitalization interventions. Threin, roof features, floor number, functions, structural systems, plan typology and façades features were observed in 2 different pier buildings in Kadiköy on the Anatolian coast of Istanbul, i.e., Moda ferry boat station, Kadiköy station for city lines.

3.2. Moda ferry boat station

Moda Pier was designed by architect Vedat Tek, one of the pioneers of the First National Architectural Movement, during the reign of the 35th Ottoman Sultan, Mehmed Reşad (1844–1918). The inscription on the building, adorned with floral motifs on both sides, bears the Ottoman Turkish phrase "Moda 1335," suggesting that it was built between 1916 and 1919. Moda Pier features a simpler neoclassical style (Fig. 2). With its rectangular plan, pitched roof, unique design reflected on all four facades, and elegant tiles decorating its window pediments, the pier has left a lasting cultural memory (Demirtaş, 2022).

Just at the beginning of the post-pandemic, the Transportation Coordination Directorate in coordination with the Istanbul Metropolitan Municipality (İBB) took the decision to launch an AR project for the pier. The historic *Moda* ferry boat station, which has been closed to sea transportation for many years, was reopened to service on the 1st of November 2022. From that date, the station started operating around 10 trips a day between Bostancı, Moda, Kadiköy and Kabataş lines, which are different ferry stations located between the two continents (Demirtaş, 2022).

The architectural design of the *Moda* Pier exhibits the defining characteristics of the Neoclassical style, which gained prominence in the late Ottoman period and was notably influenced by Western architectural movements (Fig.2). The building's facades are articulated with wide arched windows that not only enhance their aesthetic appeal but also allow natural light to the interior space, creating a bright and airy atmosphere (Fig.3).

The symmetrical layout refined ornamental detailing (Fig. 4), and distinctive architectural elements collectively underscore the building's alignment with the design principles of its era (Table 2). However, in interior space, simple yet expressive materials such as wood, brass, and ceramic tiles are used to complement both the architectural atmosphere created by Vedat Tek and the building's existing structural character (Çınar, 2023, March 28). Furthermore, the use of timber in the interior space reflects a contemporary interpretation of traditional Turkish architectural practices, thereby bridging historical motifs with modern sensibilities.

Table 2. The architectural features of Moda pier after renovation (Source: the author)

Roof features	Type: Hipped roof Cover: clay red tiles Wide overhangs
Floor number	Two story
Function	Ferry building, book/café, library
Structural system	Frame system
Plan typology	Rectangle and having a symmetrical layout
Façade features	Bridging historical motifs with modern sensibilities

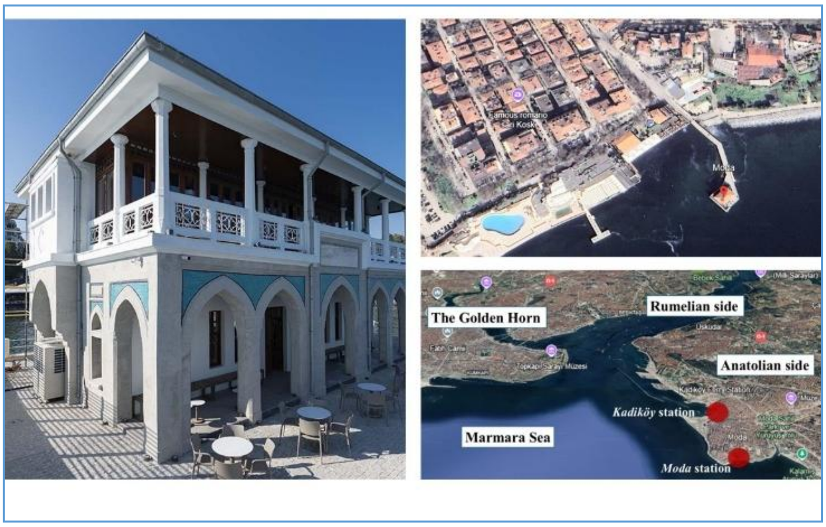

Fig. 2. Moda Ferryboat station

Fig. 3. Front view of Moda pier after the revitalization (Demirtaş, 2022)

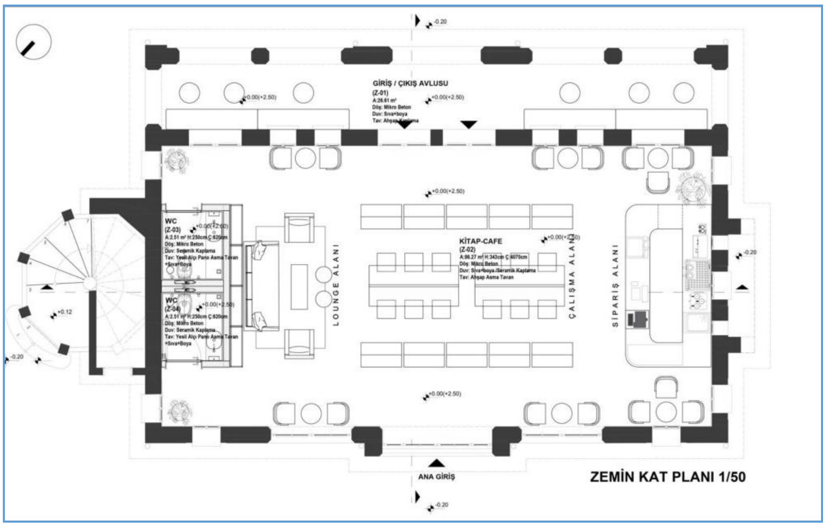

Fig. 4. The ground floor plan of Moda pier after the revitalization (*Source:* Çınar, 2023)

Table 3. The transformation of *Moda* pier after the adaptive reuse project

The starting point		
-Extending the lifecycle of the building so that it becomes stabilized, and ready to accommodate new technologies -Reduce the negative impact of the dilapidated building - Requirement for multifunctionality - Reviving the terminal building dead heritage		
Circular Economy-based actions taken		
Environmental indicators	Socio-cultural indicators	Economic indicators
- Emphasis on taking advantage of the windows' structure for a more energy efficient space. - Focusing on using local materials and techniques like	- Creation of additional functions and contemporary services in line with conservation ethics. - Repurposing while preserving the original building structure. - Re-using the building and its pier in a way that revives the nostalgia to the past and enhances the sense of identity and attachment to the collective memory.	- Transforming the space into a multipurpose area reflecting a closed-loop system where many small businesses are completing each other, i.e., the book/café space of the terminal and its relationship to the surrounding retails
Effects		
- Revitalization of the historic architectural character - The transformation of the station to a multifunctional area - Preservation of the ferry building functions and adding supplementary functions, i.e., socio-cultural functions (book café and library), tourist and recreational functions (sightseeing areas and a flexible interior) - Development of the creative sector activities		

The ground floor of the station was planned to serve as a book café and a workspace. The overall spatial layout is designed to allow the book café to function as a performance space on certain days and at specific times. By removing added walls, an open-plan layout is created. Wet areas and a service counter are positioned at the two short ends of the symmetrically planned space. The café and workspace are in the central area. Movable bookshelves and tables are introduced, making the space multifunctional and flexible. Thanks to the adaptable furniture, the layout can be easily adjusted to meet the needs of the moment—transforming the pier into both a waiting area for passengers and a potential stage for artists, as well as a sightseeing spot for visitors.

Situated on the upper level, the spacious terrace offers visitors a panoramic view of the sea, reinforcing the structure's relationship with its maritime context. keeping the historical architectural landmarks of the past when renovating the façade helped reflect the lasting impact of the city's collective memory. Therefore, only cleaning and minor repairs have been carried out (Table 3).

3.3. *Kadiköy* ferry boat station for city lines

Kadiköy ferry boat station is one of the earliest architectural interventions on the main Kadiköy public square, established on a large land reclamation from the Marmara Sea. Its structure is presently known as the Old Pier or Beşiktaş Pier (Fig. 5). Based on the inscription located on the edifice, the two-story structure was completed in 1926, during a period in which maritime transportation constituted the sole means of access between Kadiköy and the historical peninsula of Istanbul.

The building exhibits decorative facade, featuring period-specific Kütahya tiles, and for its two prominent onion domes which represent elements underscoring both the eclectic stylistic tendencies of the era and the building's symbolic prominence (Table. 4). Despite its historical and architectural significance, the pier has undergone multiple phases of restoration resulting in the loss of certain original design elements and ornamental features (Fig. 6).

Table 4. The architectural features of Kadiköy pier after renovation

Roof features	Type: Hipped roof and two onion domes Cover: clay red tiles Wide overhangs
Floor number	Two story
Function	Ferry building, book/café, library
Structural system	Frame system
Plan typology	Rectangular
Façade features	Decorative facade, featuring period-specific Kütahya tiles

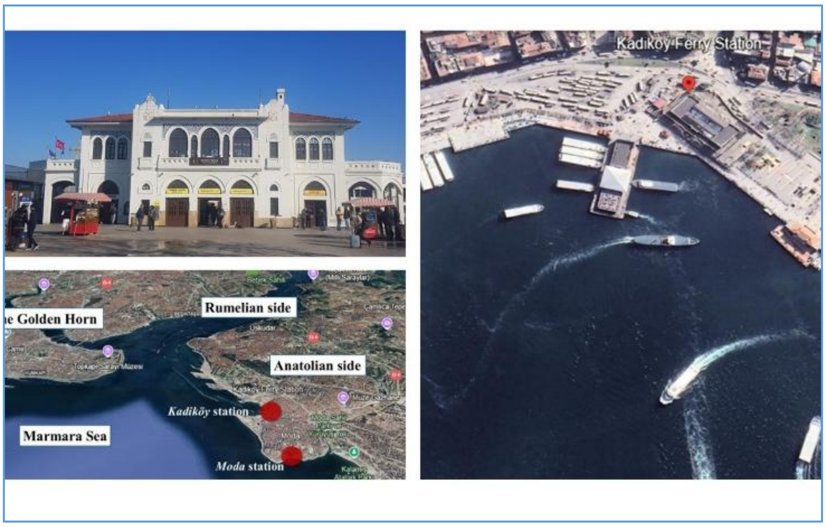

Fig. 5. Kadiköy ferry boat station or Beşiktaş pier

Fig. 6. Kadiköy ferry terminal library (UrL-2)

Modern technologies and advancements in transportation have brought significant changes to the area surrounding the pier. The development of transportation networks has increased accessibility to Kadiköy and, consequently, to the ferry terminal, resulting in a great increase in the number of visitors. With the introduction of numerous new ferry and sea-bus routes, the pier remains a vibrant and active node, continuing to serve as a preferred mode of access to Istanbul's historical landmarks. This ongoing activity contributes not only to Kadıköy's urban growth but also to the formation of a dynamic and socially vibrant environment.

Today, Kadiköy Ferry Terminal has evolved beyond its original function as a mere transportation hub. After the revitalization it went through, it has become a popular meeting point that attracts both local residents and international visitors. Neighboring many cafés, restaurants, and shops surrounding, the terminal gained a vibrant atmosphere attracting visitors. Besides, the terminal stands out as an iconic symbol closely associated with the dynamism and liveliness of Kadiköy district. As a result, Kadiköy has emerged not only as a key node in urban mobility but also as a central space for social interaction and public life (Table 5.).

Kadiköy Ferry Terminal has become a symbol of Istanbul's cultural richness through its unique fusion of historical character and contemporary urban life. For both local and international visitors, it serves not only as a historical site but also as an active space within the modern city. The ferry station continues to function as a significant architectural and cultural landmark that bridges Istanbul's past, present, and future.

Table 5. The transformation of Kadiköy ferry building after the adaptive reuse project

The starting point		
- Increasing the existing building lifecycle - Reducing the negative impact of the damaged building - Requirement for multiuse - Reviving the surroundings of the terminal's-built heritage		
Circular Economy-based actions taken		
Environmental indicators	Socio-cultural indicators	Economic indicators
Emphasis on recyclability of materials.	Creation of additional spaces and contemporary services in line with conservation ethics. Reconstruction while preserving the original building structure Reusing the building in a way that attracts more visitors, locals and tourists. Enhancing space branding by mix-use, i.e., café, library, ferry building and terrace for sightseeing	Attracting smaller businesses to the surroundings to make the area self-sufficient
Effects		
- Revitalization of the historic architectural character. - The transformation of the station to a multifunctional area - Preservation of the ferry building functions and adding supplementary functions, i.e., socio-cultural functions (book café and library), tourist and recreational functions - Supporting small businesses and generating local economic activity surrounding the ferry terminal like mobile food trucks and kiosks - The development of the creative sector activities like life music performances - Reflecting a balanced staging and branding of the historic terminal building by mixing the historical touch to the modern adequate building technologies - Enhancement of the civic pride and the sense of attachment by reviving the use of the dead-built heritage		

4. Findings and discussion

The onsite observations and the empirical research investigating the transformative power of the circular ARCH led to show that circularity-based revitalization of ferry terminals in Istanbul exhibited a creation of a closed-loop process expressed through the area's economic enhancement, creation of jobs, the equitable appropriation of heritage assets, and the increase of urban safety and security. Particularly in the case of Moda ferry terminal, the pier area presented a shift from being a leftover area to a vibrant cultural Hub and a spot for leveraging investments through CE-based AR.

The socio-economic dimensions of the circular AR of ferry boat stations in Istanbul revealed the potential of CE-driven heritage revitalization. The study showed that adopting a circular approach to AR of ferry terminals not only enhanced the historic architectural identity but also transformed these stations into multifunctional spaces. Moreover, circular ARCH enabled the preservation of the buildings' original functions while incorporating additional ones—such as socio-cultural (e.g., book cafés and libraries), tourism, and recreational uses—which contributed to increased tourist activity.

Supporting small businesses and generating local economic activity surrounding the ferry terminal like mobile food trucks and kiosks and the development of the creative sector activities like life music performances had a role to play in reflecting a balanced staging and branding of the historic terminal building by mixing the historical touch to the modern adequate building technologies. Hence, these combined factors strengthened civic pride and fostered a deeper sense of connection to local heritage. However, while AR of ferry terminals in Istanbul offers considerable potential for urban revitalization, it remains crucial to balance commercial interests with community needs to prevent adverse social outcomes.

The metamorphic cultural influence brought about by circular AR in the Istanbul case demonstrated that historical ferry stations largely retained their original identities and spatial continuity, despite undergoing multiple renovations over time due to various forms of damage. These stations, emblematic of Istanbul's rich maritime heritage, continue to serve as vital components of urban memory and significantly contribute to the preservation of the city's cultural identity.

In the arena of historic buildings revitalization through AR processes, there is no "one single standardized" solution that can fit all heritage contexts, as all built heritage sites are different and have unique features, however the results of this study may serve as a valuable resource for heritage professionals and policymakers, supporting more proactive and sustainable AR strategies that align with circular economy principles.

5. Conclusions

The foregoing research contributed to illustrating the lessons and recommendations learned from balanced circular AR of built heritage from the perspective of ferry boat terminals. Based on the observed heritage revitalization cases, AR of ferry buildings and their transformation into multifunctional areas where many small businesses are supporting the preservation of the original functions and adding supplementary ones contributed to animating the social, economic and cultural sphere of the buildings' surroundings. Therefore, interwoven socio-cultural functions (book café and library), touristic and recreational functions (sightseeing areas and a flexible interior that can be modified to receive more users) helped not only the animation of the community's sense of pride and attachment to the past, but also enhanced the attraction of tourists and non-local visitors. Thus, the main lessons learned from the present study can be resumed as follows:

- Circular AR has a role to play in both socio-economic and cultural revitalization, namely the heritage tourism promotion, the local business enhancement, and the local civic pride conservation and enhancement.
- Following a zero-waste conservation policy based on renewable energy use is an entry point to include adequate environmental impact indicators based on the circularity strategy. To bridge the existing gap, heritage conservation needs to be inscribed in an overall conservation strategy integrated into a holistic development approach.
- Istanbul's ferry boat stations have the potential to play role models for other cities aiming at setting a balance between heritage conservation and the demands of circularity-based sustainable development.

This study examined circularity-based AR indicators in two examples of two-story ferry terminals on the Anatolian coast of Istanbul highlighting their significance in terms of preservation and the circular approaches to sustainability. The case studies exploration helped show how appropriate material interventions and added functions for the reuse of ferry boat stations are key to guaranteeing a balance between the cultural values of heritage assets and the modern needs. However, the challenges that arise from the extensive use of ferry boat stations for purposes else than commuting drive the built heritage of shores to "touristification" trends. Balancing built heritage conservation with modern requirements demands careful planning and community involvement to ensure that projects meet contemporary needs while respecting historical contexts. Future research could enrich the architectural and urban development discourse by conducting comparative analyses between these piers and other coastal structures across the city. Additionally, integrating more quantitative data and analytical methods may offer deeper insights into the role of pier buildings in shaping urban development.

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Rize architectural historiography: What archive sources tell us

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The isolation of Rize throughout history from the Anatolian and Caucasian regions has resulted in limited references to the city in historical sources. Undoubtedly, for a study on the history of Rize, maximum benefit must be drawn from the limited data obtained from these sources. This study aims to identify and compile primary source groups that can shed light on Rize's urban history and explain how these sources can be utilized.
The study explains which historical sources can shed light on which topics. In this context, the historical sources are examined within three different time periods: the pre-Ottoman era, the Ottoman era, and the Republican era. The data have been analysed in the context of the historical information they contain, the findings obtained from these sources have been evaluated, and the periods in Rize's history where continuity or disruption occurred have been identified.
Contrary to common belief, the study reveals that Rize has origins in the Ancient Period. Early sources largely consist of Greek travel books, while Medieval sources are scarce. Post-Ottoman conquest records provide more information, and in the Republican era, visual documents allow a more concrete observation of Rize's physical environment.
Throughout the study process, all kinds of data that could provide clues about the past of the city of Rize have been carefully analysed, and any primary sources that could provide information about Rize from its foundation to the present day have been identified. The study explains what each of these sources provides information on.

Keywords: Architectural historiography; Rize city history; Archive sources; Primary sources; Secondary sources

1. Introduction

Rize is a coastal city located in the eastern Black Sea region. Characterized by a rugged, mountainous topography and heavy rainfall, the city features dense forests and limited flat land confined to a narrow coastal strip. Due to the high mountains stretching east-west to its south, Rize historically remained isolated from Anatolia. This isolation fostered a unique and independent cultural identity, while resulting in a scarcity of written and visual historical sources. Consequently, Rize has rarely been a focus of scholarly research.

The city's geography has also shaped its urban development. The limited flat areas led to concentrated construction along the coast, particularly toward the north, as expansion southward was restricted. As a result, much of the historical building stock was demolished to make way for larger, modern structures meeting the needs of a growing population. This has left very few historical buildings standing today. The lack of surviving structures and limited written sources has contributed to the misconception that Rize has a shallow historical background. Many locals and some researchers perceive the city as historically insignificant, a view frequently encountered in studies on Rize's past. This perception has further diminished interest in preserving the city's historical heritage, accelerating the destruction of remaining historical structures.

Current evidence, however, indicates that settlement in Rize dates back to the 2nd century AD. Its sheltered bay made it an attractive site for early settlers. During the Byzantine and Ottoman periods, Rize's strategic position near the imperial borders enhanced its significance, particularly in terms of security and maritime activity. The ongoing uncertainty regarding Rize's settlement history largely stems from the underutilization of available data and the lack of comprehensive studies. Throughout history, Rize has been part of major civilizations including the Eastern Roman Empire, the Empire of Trebizond, the Ottoman Empire, and the Republic of Turkey, shaping a multilayered urban memory. Although gaps remain, limited but meaningful historical data from the Ancient Period to the present exists. When assessed these sources (travel books, archival documents, and existing literature) hold considerable potential for filling major gaps in the historiography of Rize.

Accordingly, this study aims to analyse archival records that could contribute to the writing of Rize's urban history and to highlight their historiographical potential. Within this scope, archival materials are examined across

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three periods: the Pre-Ottoman Era, the Ottoman Era, and the Republican Era. Documents are analysed with a focus on settlement patterns, construction activities, and the dynamics of building and demolition, all crucial for illuminating Rize's architectural history.

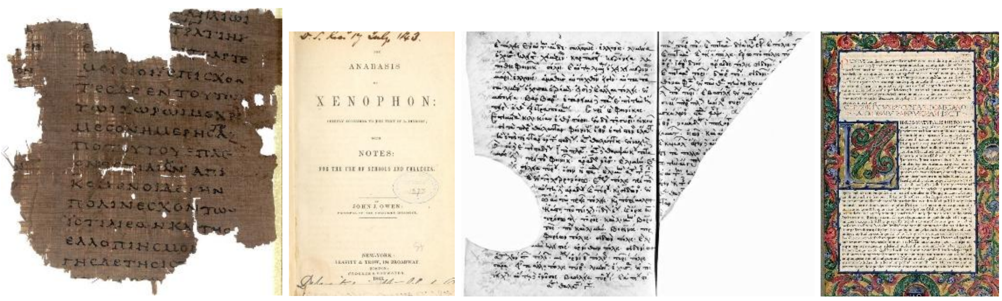
2. Primary Sources from the Pre-Ottoman Period

The absence of archaeological excavations in the city center has resulted in extremely limited concrete evidence regarding Rize's ancient settlement. Today, the only surviving structure from this period is Rize Castle, located in the city center. Although limited, the castle constitutes an important historical trace, offering insights into the city's early settlement pattern. Moreover, much of the existing knowledge about Rize's pre-Ottoman history relies on ancient Greek sources and traveler narratives contained within these texts. These accounts provide valuable information about the region's ancient existence and historical topography. In addition, Rize Castle holds significance for understanding the early history of the city.

2.1. Travel Books:

The most significant written sources that shed light on Rize's early history are undoubtedly travel accounts. Due to Rize's location at the center of the coastal line of the Colchis and Pontus regions, where maritime activities were crucial in Antiquity, it became a notable stop for many travelers. These accounts, mostly written in Ancient Greek, describe voyages undertaken by sea. Although ancient Greek texts are among the few sources that illuminate Rize's early history, it cannot be said that ancient authors provided detailed or comprehensive information specifically about the city. The references to Rize in these texts are generally limited and indirect. The name of Rize first appears in Arrianus's work dated to AD 131 (Arrianus, 2025). Prior to this, although Herodotus, Xenophon, Scylax (Pseudo-Scylax), Strabo, and Pliny do not refer directly to Rize as a settlement, their accounts offer insights into the political conditions and general characteristics of the region. In later periods, works by Arrianus, Ptolemaeus, and Procopius begin to mention Rize more explicitly. These travel accounts cover a timeline from the 6th century BC to the 4th century AD. The medieval period, however, remains obscure for the city's history, as no primary written sources concerning Rize from this era have been discovered.

Herodotus's *Histories*, written in the 5th century BC, provides comprehensive information about the political structures, social life, and major wars in the Black Sea and Anatolian regions (Herodotus, 1973). Although Herodotus does not mention Rize directly, his references to the ancient Colchis region and its ethnic groups offer valuable insights into the socio-cultural structure of the area during Antiquity (Herodotus, 1973). He describes the migration of the Scythians into the Colchis region from the north and their subsequent dispersal across Asia following their defeat by the Medes. While Herodotus's historical framework provides a general perspective on the early history of the region, more direct references to Rize emerge only with Arrianus's *Periplus of the Euxine Sea* written in AD 131. While the historical framework provided by Herodotus offers a general perspective on the early period of the region, the accounts of travelers up until Arrianus's *Periplus of the Euxine Sea* (AD 131) do not directly address the city of Rize. Works such as Xenophon's *Anabasis* (4th century BC), the *Periplous* attributed to Pseudo-Skylax, Strabo's *Geographica* (Strabo, 2025), and Pliny the Elder's *Naturalis Historia* (Pliny, 2025) provide an indirect historical foundation by describing the geography, climate, early population movements, and interactions between Colchis and neighbouring civilizations. These texts are significant sources that can be considered indirect references for the historiography of Rize and its surroundings in Antiquity (
Fig. 1).



(a) (b) (c) (e)

Fig. 1. Ancient Greek travel books's ancient manuscripts (a) A fragment from Herodotus's *Histories*, located in the Papyrology Room of the Sackler Library, (b) Xenophon's Anabasis, published in New York by Leavitt & Trow in 1843, (c) Ancient Greek Periplus of Scylax National Library of France, Department of Manuscripts, (d) First page of the Pliny's "Historia Naturalis" printed by Johann of Speyer

The earliest written source providing direct information about Rize is Arrianus's *Periplus of the Euxine Sea*, written in AD 131. This work is of great importance as it is the first reference to the name Rize in ancient literature.

Arrianus's observations of the region include not only geographical and strategic information about the Black Sea coast but also local settlement names, marking Rize's first documented appearance in history. Based on the mention of the Rhizius River, and considering the distances and place names given by Arrianus, it is understood that the river passes through what is now the city center of Rize. This is significant as it suggests that the city of Rize is named after a river and provides insight into the region where the city was first established (Arrianus, 2005).

Ptolemaeus, in his *Geography* written in the 2nd century AD, mapped the known world of his time and discussed major settlement areas. In his work, he mentions the Rizous Harbor along with important Black Sea ports, recording settlements and the distances between them (Ptolemaeus, 2025). His reference to Rizous Harbor is important both in showing the existence of this region in antiquity and in establishing Rize as a port city by AD 150. This information helps us understand the continuity of settlement in the region and places Rize within the economic and commercial network of the Black Sea region (

Fig. 2).

Procopius's *History of the Wars* and *On Buildings*, written in the 6th century AD, are also key written sources for information about Rize during the early Byzantine (Eastern Roman) period. *History of the Wars* is important for its detailed description of the boundaries of the Roman city of Rhizeum, while *On Buildings* is significant for its account of the urban development activities in Rize during the reign of Emperor Justinian.

(a) (b)

Fig. 2. Greek texts that directly mention Rize City (a) Start page of Periplus of the Euxine Sea (Arrianus, 1533), (b) Ptolemaeus's Geographia map showing the region of Colchis

In a region with limited archaeological and written data from the pre-Ottoman period, it is necessary to address the Rize Castle, which sheds light on the area's historical past. Although it does not serve as a written document, the physical presence of the castle -its architectural features, location, and construction techniques- provides the opportunity to draw inferences about the city's settlement history and physical fabric during the pre-Ottoman period (

Fig. *3*). In Procopius's "On Buildings," the newly constructed defensive structure he mentions is likely the Rize Castle that still stands today, and it is understood to be located in the area where the city was originally founded. In this regard, architectural structures, in addition to written documents, can be considered valuable sources that complement the limited information provided by early period travel books.

Fig. 3. 2024 Year Rize Castle (Author Archive)

3. Primary Sources from the Ottoman Period

After Sultan Mehmed the Conqueror's (Mehmed II) conquest of Trabzon in 1461, the districts of Atina (Pazar), Hemşin, and Arhavi in the Rize region were incorporated into the Ottoman Empire shortly thereafter. According to historical sources, it is known that the conquest of Rize occurred approximately one month after the capture of Trabzon (Ak, 2000; Aksu, 1968; Bostan, 2002).

After the Ottoman conquest, the city's historical topography can be traced in greater detail compared to the previous period, thanks to the existence of primary sources and a significant amount of literature. Early Ottoman documents are an important source group for the city of Rize, where data from the Ancient and Medieval periods are scarce. Inscriptions, waqf records, Tahrir Registers (cadastral records), Şer'iyye Registers (court records), travel books, annuals, maps, and visual materials, which provide a rich source of information about Rize and its surroundings, are the primary sources for the city's architectural and art history. In addition to these documents, which nearly continuously reveal the physical development of the city between the 15th and 20th centuries, military and administrative documents containing information about Rize's defence organization, castles, and military units sent to the region also hold valuable data and clues. Together, these sources contribute to the development of a comprehensive perspective on the city's historical continuity, physical fabric, and social dynamics.

3.1. Tahrir Registers (Cadastral Records):

The oldest Tahrir Registers that provides information about Rize's demographic structure after the conquest is the 1486 Tahrir Register.(Bostan, 2002). The Tahrir Registers from 1515 to 1583, compiled after 1486, are also important documents that illuminate 16th-century Rize (Bostan, 2002; Ak, 2000).

The registers kept during this period of Ottoman rule over Rize were created to document provincial administration and to systematically manage the taxation system. They contain detailed data on population, property, and production relations. Particularly, Hanefi Bostan's 2002 work, “XV-XVI. Asırlarda Trabzon Sancağında Sosyal ve İktisadî Hayat”, offers significant evaluations regarding the changing demographic structure of the city following the Ottoman conquest, the neighbourhoods inhabited by Muslim and non-Muslim communities, and the likely locations of these neighbourhoods, based on these registers (Bostan, 2002).

The names of districts, neighborhoods, and villages in the tahrir registers provide important clues for understanding the changes in the boundaries of the regions that encompass the center of Rize (Nefs-i Rize), the western part of the city (Akrotil), and the eastern part of the city (Emare) during the Ottoman period, as well as the subsequent subdivision of these areas into smaller neighbourhoods. These documents not only offer indirect information on the locations of neighbourhoods within the city but also contain detailed data on population, household numbers, religious affiliations, and economic activities, shedding light on the social structure. Additionally, the records provide insight into the development activities and include information about waqf (vakıf) properties. The tahrir registers meticulously recorded the assets and income sources of waqfs belonging to religious and educational institutions such as mosques, madrasas, and tekkes established in Rize. Through these records, traces of the history of some buildings that still exist today can be traced, and it is also possible to identify structures that no longer exist or those that were demolished and rebuilt over time. All these data allow for a chronological and comparative evaluation of the physical and institutional development of Rize, offering an indispensable reference source for urban historiography.

3.2. Salnames (annuals) of the Trabzon Province

The Salnames of the Trabzon Province are an important group of sources providing information about the Black Sea region during the 19th-century Ottoman period. In the Salnames of the Trabzon, Rize is mentioned as a district governed from the center of the Trabzon Sanjak (district) between 1869 and 1876. After the Ottoman Empire ceded Batum to the Russians in 1877, Rize was separated from the Trabzon Sanjak and became the center of the Lazistan Sanjak. Consequently, in the Salnames (annuals) of the Trabzon Province from 1877 to 1904, Rize was elevated from a district status to a sanjak (subprovince) within the Lazistan Sanjak (1877 Salname of the Trabzon Province)

The Salnames of the Trabzon Province, covering the period from 1869 to 1904 and containing information about Rize, were translated into Turkish by Kudret Emiroğlu and published in Latin script by the Trabzon Foundation between 1993 and 2009. In these salnames, it is possible to find a wealth of information about the city's history, as well as detailed records of structures such as medreses, mosques, hammams, fountains, and inns, along with population data for the entire sanjak, distance tables, and annual production statistics. Additionally, some sections of the salnameler, titled “Malumat (information) about Rize,” contain specific explanations about the city’s history or current events. Expressions like "Hamam-ı Cedid," "Medrese-i Atik," and "Atik Han" provide valuable insights into the structures that existed in the city during the Ottoman period.

3.3. Rize Şer-iyye Registers:

Another important source group that provides highly interesting and original information for the writing of urban history is the "Qadi registers" or "court records." These sources, covering the period from the classical era to the Republic, shed light on the multifaceted relationships between individuals and society, as well as individuals and the state (İpşirli, 1991). As registers that document all information under the knowledge of women, such as legal disputes, construction, exploration, and repair decisions, they serve as memory sources containing any matters related to urban life.

It is known that the earliest Rize Şer-iyye register was kept in 1854. The Rize Şer-iyye Registers, maintained until the early 20th century, explicitly state the names of the parties involved in a lawsuit, the neighborhoods where the parties resided, and the names of the administrative units the neighborhoods were part of. This information is crucial for understanding the formation of the city during that period. Furthermore, although no information may be found about the physical structure of a building mentioned in the records, whether related to social events, foundations, repairs, or property sales, the mention of its name and location still helps identify the city's layout during that period. Additionally, references to philanthropists's contributions to the construction of mosques and madrasas, as well as the income from their foundations, enable the identification of historical buildings that once existed in the city or provide insights into the old names of such structures.

For example, in the 1495 Rize Şer-iyye Registers, the entry stating that a baby was found in the courtyard of the "Orta Cami-i Şerîf" reads "…kasaba-i mezkûre derûnunda kâin Orta Câmi'-i Şerîf havlusunda bulunmağla iltikāt olunub ebeveyni ma'lûm olmayub malı dahî olmadığı hâlde liecli'l-irdâ' ve't-tebennî…" This statement indicates that the Orta Camii was standing between 1869 and 1871, as recorded in the Shari'a register, and that it was referred to by the same name used today (Rize Şer'iyye Register No. 1495).

3.4.Travel Books

Travel Books, like in the Ancient Period, are important in the Ottoman Period as well for understanding the general structure of the city. Rize became a city that attracted the attention of various travelers and observers during the Ottoman period; these individuals documented their impressions of the city. Some of the main figures who provided information about Ottoman Rize include Defterdar Sarı Mehmed Paşa, Per Minas Bijişkyan, Victor Fontanier, James Brant, Karl Koch, and Şâkir Şevket. These works provide information about Rize's physical and natural environment, maritime and port activities, commercial movements, and agricultural production.

Defterdar Sarı Mehmed Paşa's "Zübde-i Vekayiât," written between 1656 and 1704, is an important source for Ottoman historiography of its period. Having served in the state's finances, Sarı Mehmed Paşa provides detailed information about financial policies and the provincial organization. In this context, he mentions the active use of Rize Port, located at a strategic point near the border during the Ottoman-Russian wars, for military supplies and ship docking (Defterdar Sarı Mehmed Paşa, 1995).

Per Minas Bijişkyan, who carried out observations along the northern and southern coasts of the Black Sea between 1817 and 1819 due to his role (as a vicar-priest) in the region, offers detailed insights into the port cities he visited in his work "Karadeniz Kıyıları Tarih ve Coğrafyası." In the Rize section of his work, Bijişkyan provides information about the city's location, its neighborhoods, the agricultural products grown in the region, and important buildings constructed in the city (Bijişkyan, 1969). He also offers interesting insights into the origin of Rize's former name, Rhizius (İrizios).

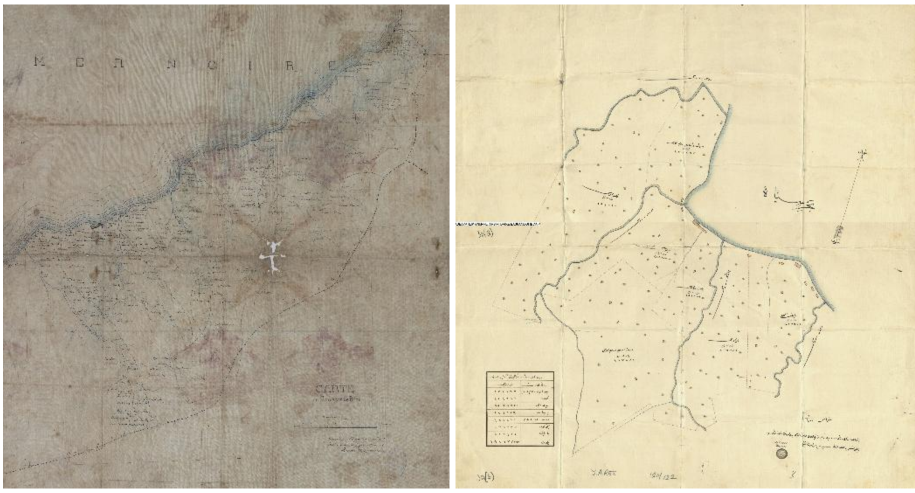
Among the city's visitors were political officials, soldiers, consuls, natural scientists collecting plants and insects, archaeologists, historians, geographers, and geologists. Victor Fontanier, a French consul, wrote "Notice sur la côte de la Mer Noire, appelée Lazistan" (Notes on the Black Sea Coast, Known as Lazistan), a unique and significant source containing travel observations about the eastern Black Sea coast of the Ottoman Empire in the 19th century (Yılmaz, 2014). In 1831, during his visit to Lazistan (Rize), Fontanier thoroughly explored the region. His work describes the city's built environment and geography in detail. Fontanier discusses the appearance of houses built by the local people, the state of Rize Castle, the location of the marketplace, and the natural environment. Similarly, James Brant, another consul stationed in the region, wrote "Journey Through A Part of Armenia and Asia Minor," a travel book containing detailed observations of his travels in Ottoman lands in the first half of the 19th century. Brant, during his tenure as England's consul in Trabzon, documented his travels in the eastern Anatolian region and Black Sea coasts, providing insights into Rize as well (Brant, 1836). He mentions Rize's fertile land, the agricultural products grown there, the renowned linen fabric produced, and the large marketplace on the city's coastal area.

Karl Koch, a German botanist and naturalist, wrote about his observations in Ottoman lands during his travels in 1843–1844 in his book "Wanderungen im Oriente während der Jahre 1843 und 1844" (Prof. Dr. Karl Koch's 1843-1844 Journey in the Eastern Black Sea Mountains and Northeastern Anatolia). His travel book provides detailed descriptions of 19th-century Rize, documenting the city's physical appearance, natural environment, agricultural production potential, and daily life practices of the people. Koch observed Rize's relationship with the sea, its settlement pattern, and the people's main livelihoods. The book includes information on Rize's history and the state of Rize Castle during that period. Koch's accounts not only shed light on the physical environment but also on the simple lifestyle, clothing, and cultural traditions of the local people, contributing to the understanding of the region's historical and social fabric. The work is significant for offering insights into how Rize was perceived in Europe during the mid-19th century and how scientific circles evaluated the region.

Observations about the region were not limited to foreign travelers; local historians also provided valuable information about Rize and its surroundings. One such historian, Şâkir Şevket, did not travel to Trabzon like the other travelers but wrote about the region with the local knowledge acquired from being born and raised in Trabzon. Born in 1847 in the Ortahisar district of Trabzon, Şâkir Şevket sheds light on the history of various settlements along the eastern Black Sea coast, including Rize, in his 19th-century work “Trabzon Tarihi.” Şâkir Şevket discusses Rize's historical, geographical, and commercial aspects and mentions an old building in the city, possibly Rize Castle, along with Bijişkyan’s views about the city's name.

3.5. Maps and Sketches:
The desire to observe urban space and to depict these observations has existed since the earliest periods of history. Maps are a product of humanity’s efforts to better understand and familiarize itself with its surroundings. Most maps are found either in private archives or scattered across various thematic studies.

The earliest surviving map produced for Rize, based on modern cartographic knowledge, dates to 1894, and in this map, only the place names within the city are indicated. In later maps and sketches, it is possible to observe that structures began to be depicted as well. Such maps serve as important sources that help explain the city's spatial changes and transformations. By superimposing maps prepared for different periods, it becomes possible to evaluate aspects such as the building stock, transportation networks, and other urban potentials (
Fig. 4,
Fig. 5).



(a) (b)

Fig. 4. Maps from the Ottoman Period (a) The 1894 Map of the Sanjak of Lazistan (BOA, HRT.h. nr. 2587), (b) The Neighbourhoods in the City Center of Rize in 1903 (BOA, Y.A.RES. nr. 120-122)

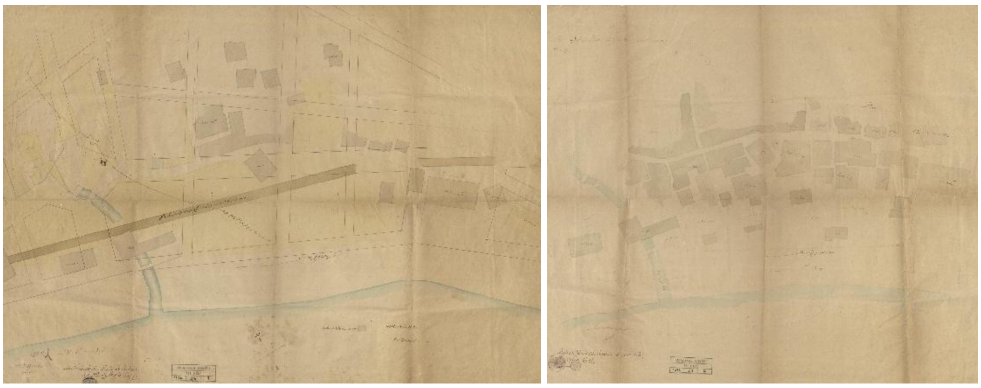


Fig. 5. The 1918 Map Depicting the Structures in the City of Rize (BOA, ML.EEM. 1336-39)

3.6. Photographs:
Visual documents that offer a glimpse into the past serve as realistic and objective evidence for historians, making them significant sources in historical research. Photographs are among the most tangible visual materials that enable the physical perception of a city. The earliest known photograph of the city of Rize appeared in the Servet-i Fünûn Journal in 1896 (Fig. 6).

In addition, the images included in Sultan Abdülhamid II's photographic album are among the oldest visual records of the city of Rize. Their direct depiction of historical structures makes them particularly significant for the architectural history of the city (Fig. 7).

Apart from these documents, it is believed that the first civilian photograph of the city was taken in 1907 (Fig. 8).

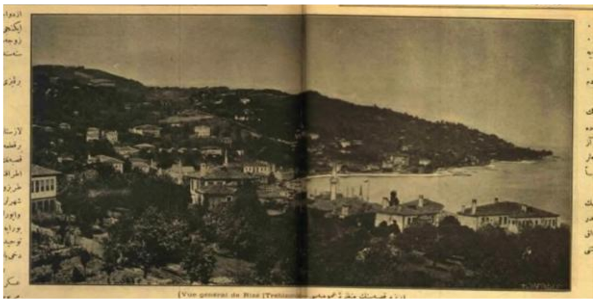


Fig. 6. The general view of the city of Rize in 1896 (Servet-i Fünûn Journal, 1896)

Fig. 7. The photographs of Rize featured in the album of Sultan Abdulhamid II (URL-1)

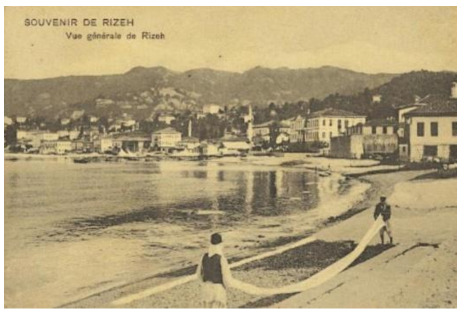


Fig. 8. The first civil photograph thought to have been taken in the city of Rize (Recep Koyuncu Archive)

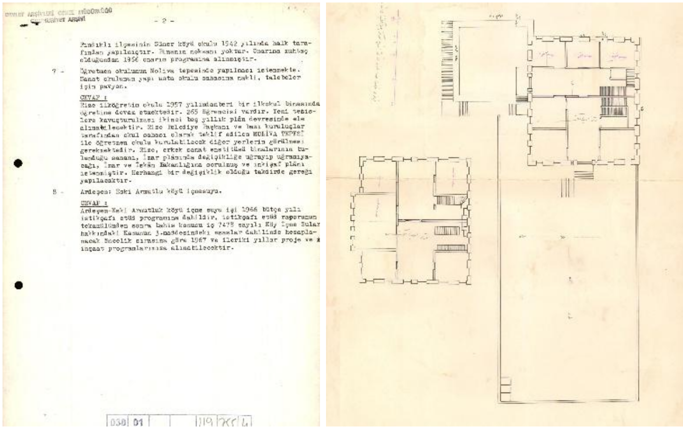
Rize photographs, as visual documents of the era, provide crucial data to be analysed alongside other written and visual sources. They not only trace the visual traces of documented structures but also help identify unknown buildings through maps and written sources in their environmental context. Ottoman-era photographs offer visual data on Rize's social structure and daily life. These images allow a more concrete evaluation of the clothing, agricultural activities, social events, and daily tasks of Rize's people.

4. Primary Sources from the Republican Era

Until the Republican era, Rize was known as the Lazistan Sanjak; it became a province one year after the declaration of the Republic (Aksu, 1968). In 1933, Rize was merged with the Artvin province to form a single administrative region, but by 1936, the provinces were separated again, and the city regained its original name, Rize (Rize Gazetesi, May 25, 1933; Rize Gazetesi, January 25, 1936).

After Rize became a province, significant urban development activities began. The development of tea cultivation, which was tested in the 1920s and became widespread in the 1940s, strengthened Rize economically. After 1960, significant advances were made in urbanization. Urban development, agricultural transformation, and urbanization during this period can be traced through primary sources such as official correspondence, municipal reports, local newspapers, maps, and photographs.

4.1. Administrative and Bureaucratic Documents:
The Presidential Republican Archive is key to understanding Rize's development, its relationship with central administration, regional responses, and the impact of government policies. The archive contains documents on the state's administrative plans, local government relations, and public investments. Reports, correspondence, and budget decisions from civil administrators in Rize provide important data on the city’s economic and social transformation. It also includes visual materials like photographs, drawings, and plans of the city's buildings. (Fig. 9).



(a) (b)

Fig. 9. Administrative Documents from the Republican Era (a) Correspondence Identifying the Needs of Rize Province in 1966 (BCA, 30-1-0-0. 119-755-4), (b) Plans of the Rize Secondary School Building from 1928 (BCA, 180-9-0-0. 97-473-7)

4.2. Municipal and Provincial Yearbooks:
Municipal and provincial yearbooks are official publications prepared periodically, documenting the urban development activities in Rize, as well as the city’s agricultural activities, socio-economic structure, and social change. These yearbooks include information on infrastructure projects within municipal services, as well as services in areas such as education, health, sanitation, and transportation, along with population data, budget information, and aspects of social life in the city (Fig. 10, Fig. 11).

Yearbooks, published in 1967, 1973, and 2002, are important reference sources for tracking the physical and institutional changes/transformation of Rize during the Republican era. The statistical tables, city maps, and visual materials such as photographs included in the yearbooks provide detailed information about the city's physical fabric.

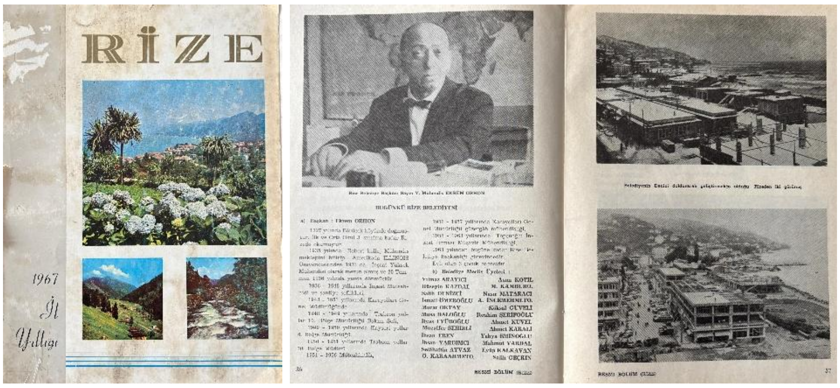


Fig. 10. 1967 Rize Provincial Yearbook

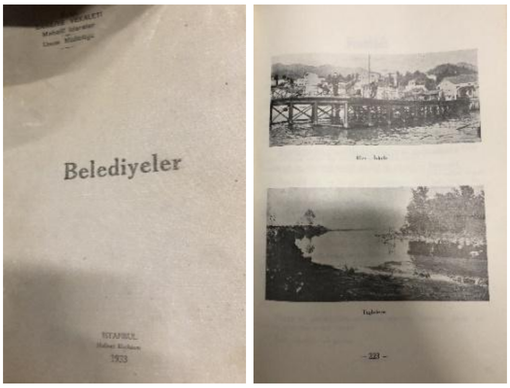


Fig. 11. 1933 Municipal Yearbook

4.3. Newspapers and Journals:

The written press holds significant importance in historical research as it directly reflects the events, debates, and public sentiment of a period. Local newspapers and journals in Rize during the Republican era form a live archive of local history by documenting the city's agenda, issues, developments, and expectations, while reflecting the political, social, and cultural structure of the time. From these newspapers, it is possible to trace the development of urban activities, as well as the destruction, construction, and restoration of important buildings. The Rize Gazette, the city's first newspaper, was published in 1931 and continued until 1942. As the only newspaper in Rize during the early Republican period, it contains valuable information about the city’s urbanization process. After the 1950s, important local newspapers such as Rize'nin Sesi, Rize, Zümrüt Rize, Şirin Rize, and Memleket Gazetesi emerged. Additionally, major national newspapers such as Akşam, Cumhuriyet, Son Posta, Hakimiyet-i Milliye, and Ulus, which provided significant information about Rize, were also notable during this period (
Fig. 12).


Rize

Rize mektupları

Rizedeki imar faaliyeti çok beğenildi

Şehircilik mütehassısı B. Lâmbert Belediye reisini gördüğü işlerden dolayı tebrik etti

(a) (b)

Fig. 12. Local and national newspapers providing information about Rize: (a) Rize Gazetesi, dated August 6, 1931, (b) Akşam Gazetesi, dated October 9, 1938.

4.4. Travel Books:

In the early years of the Republic, memoirs and travel writings by authors who travelled to Rize provide valuable insights into the city's social fabric and daily life. These texts detail Rize’s natural environment, architecture, street life, the clothing of its people, hospitality, and economic activities. Notable travel writings about Rize from the Republican era include Mirza Gökgöl's " Doğu Karadeniz Bölgesinde Bir Araştırma Gezisi" (1937), Selahattin Çoruh’s "Ankara’dan Rize’ye" (Çoruh, 1948), and Abdullah Taymas's "Yeşil Rize ve İli Province" (Taymas, 1950) (
Fig. 13). Also, "The Byzantine Monuments and Topography of The Pontos" (Bryer & Winfield, 2020), a two-volume work prepared by Anthony Bryer and David Winfield in 1985, although not a direct travel books, provides significant information about the city's settlement history. It identifies existing and lost structures, offering valuable insights into their condition during the relevant period.

Fig. 13. The travel account *Ankara’dan Rize’ye*, authored by Selahattin Çoruh

4.5. Maps and Urban Plans:
Maps, plans, drafts, and sketches have become crucial sources for local history, particularly for the 19th and 20th centuries. In this context, the development of modern cartography during the Republican era and the presence of urban planning maps are highly significant. These documents help us understand the urban planning perspective of the time and the development of urban and rural areas in the city.

According to the Municipal Law enacted in 1930, which assigned municipalities the responsibility of preparing city plans, urban planning efforts in Rize began in the 1930s. French urban planner Lambert, Governor Mehmet Hurşit, and other municipal leaders played key roles in these efforts (Bay, 2023). Based on available data, it was decided in 1939 to prepare a cadastral map of Rize’s 300-hectare residential and non-residential area (Ulus, May 26, 1939). In June 1939, the contract for preparing this cadastral map was awarded to engineer İbrahim Rahmi Arı. However, while the cadastral map was completed, the urban plan was not prepared until 1946. Arı’s cadastral map has not survived to the present day. In 1946, the urban plan for Rize was prepared and approved by Nezihe and Pertev Taner. The plan was published in the Arkitekt magazine in 1947. The map is valuable not only for representing the period but also for explaining the urban planning policies that aligned with the era’s political context (Kaçıran, 2024) (Fig. 14,

Fig. 15,

Fig. 16,

Fig. 17).

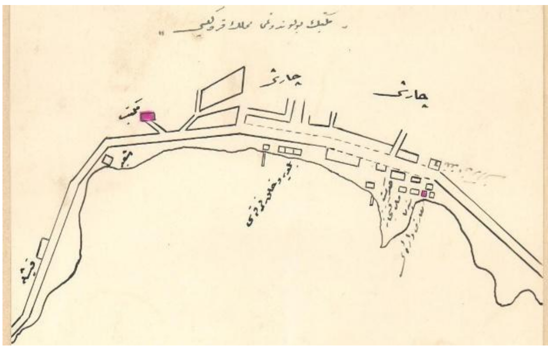
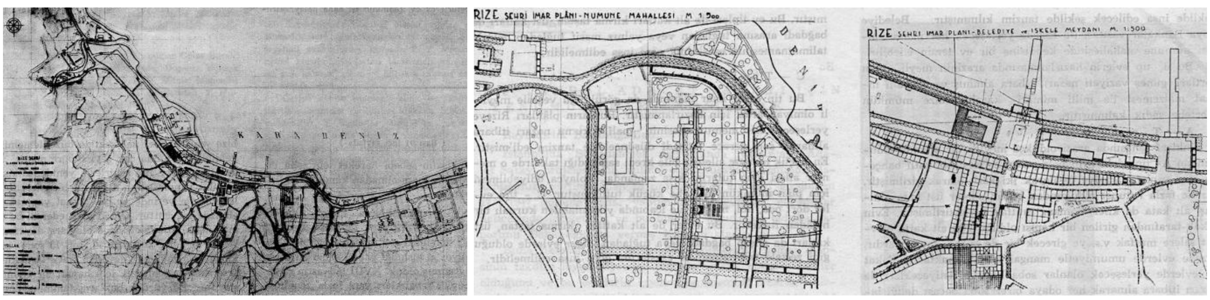


Fig. 14. A sketch showing the location of the Rize Middle School in 1928 (BCA, 180-9-0-0. 97473-7)



(a) (b)

Fig. 15. The urban development plan prepared by Nezihe and Pertev Taner in 1946 (a)

1946 Urban plan at a 1/2000 scale (Taner & Taner, 1947), (b) 1/500 scale plan of the pier, square, and Numune Neighbourhood (Taner & Taner, 1947)

Fig. 16. 1971 Rize Urban Plan (Yetman, 1971)

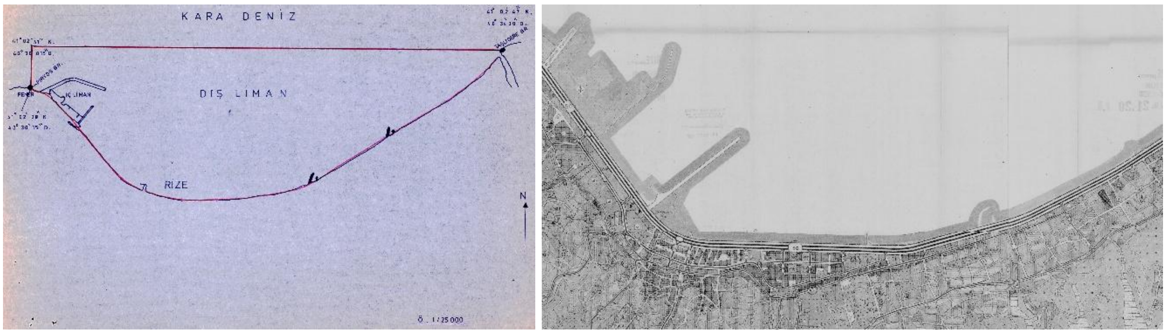
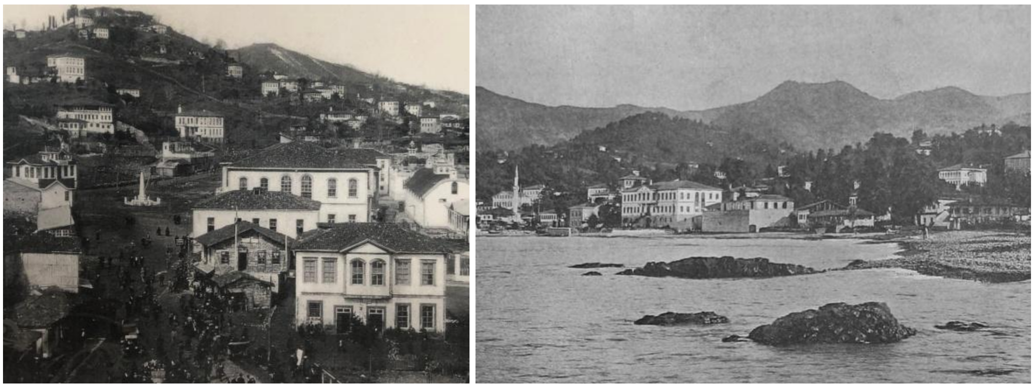


Fig. 17. City maps and plans after 1950 (a) A sketch showing the ports in Rize in 1985 (BCA, 30-18-1-2. 526-3294), (b) The 1987 urban plan prepared by Fahri Yetman.

4.6. Photographs:
Photographs from the Republican period offer a relatively rich visual archive compared to earlier eras and can be categorized into themes such as individual buildings, panoramic city views, and scenes from social life. The increase in photographs of the city during this period makes those taken from the early years of the Republic essential sources for studies on Rize’s urbanization, architectural development, infrastructure investments, and daily life practices (
Fig. 18). Images of public ceremonies, mass events, and natural disasters illuminate the city's social structure, while panoramic views provide information on street texture, the location of extant or lost structures, and architectural features. Advances in photography, allowing images from similar angles or aerial views across time, enable analysis of the city's physical transformation. By capturing space, time, and people within a single frame, these images serve as essential visual sources for tracing the layers that shape the city's identity.



(a) (b)

Fig. 18. The City of Rize in the 1920s (a) Rize Square (Fatih Sultan Kar archive) (b) The City of Rize from the Eminettin Neighbourhood Coast (Recep Koyuncu archive)

5. Conclusions
The archival documents are indispensable sources for historians in addressing the issue of finding “sufficient” and “accurate information” in the historical analysis of cities. These documents allow the tracing of events that

occurred centuries ago, from their causes to their consequences. Not only can these documents provide valuable information about the architectural history of cities, but they also offer insights into their economic, social, and political conditions. Particularly, the primary sources discussed here, along with studies on social, political, and economic history, provide essential information for architectural history researchers, especially those involving direct transcription works.

Rize city has experienced a unique development process in many aspects throughout history due to the natural isolation caused by its geographical structure. This isolation has led to limited written and visual sources related to the city's history, which, in turn, has contributed to the perception that Rize has no significant history and that the city's origins are not very ancient. However, the primary sources available today reveal that Rize has been a settlement area since the Ancient Period and has maintained its existence under the influence of various civilizations throughout history. Therefore, despite the scarcity of historical data, although the past of Rize city remains dark and filled with uncertainties, the city possesses an undiscovered heritage waiting to be explored.

After the first mention of Rize in historical sources in 131 ADS, the city is referenced in various ancient Greek travel books until the 6th century. Due to the lack of sufficient data from the Middle Ages, the city's history during this period appears obscure, but after the Ottoman conquest at the end of the 15th century, records about the city have survived to the present day. The first photograph of Rize, which provides an idea about its physical structure and building stock during the Ottoman period, emerged at the end of the 19th century, and with the increase in visual documents since then, it has become possible to gain concrete insights into the city's physical structure. The Republican Era represents a period when abundant data about Rize became available, and the physical environment of the city began to be fully illuminated. The transformation process in the city's physical structure occurred over an extended time frame, from the initial settlement period to the present day, within a social, economic, and administrative framework that involved many societal dynamics. The archival documents in question make it possible to analyse the dynamic historical topography of the city—monuments, residences, streets, squares, ports, etc.-and its changes/transformation.

This study presents a comprehensive evaluation of documents mostly found in personal archives or scattered in various thematic works. However, it cannot be said to be exhaustive. It is highly probable that there are still undiscovered documents in foreign archives. The existing and awaiting documents are undoubtedly unique in clearly revealing the physical transformation of the city of Rize, which we know has undergone significant interventions.

Acknowledgments
This study is based on the Adem Kaçıran's master thesis completed under the supervision of Assoc. Prof. Dr. Fulya Üstün Demirkaya in 2024. However, in the course of preparing the paper, the references, as well as the data and information, have been updated to the extent possible.

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Customized Kutahya pozzolan and metakaolin-based geopolymers for stone conservation: Initial findings on mechanical properties

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Abstract. Geopolymers are inorganic materials utilized primarily as alternatives to cement, owing to their workability, customizability, non-toxicity, and high strength characteristics. These properties offer innovative alternatives to existing stone repair materials, which are usually cement-based mortars that do not adapt to the original stone material and cause many serious damages. Therefore, this study aims to produce tailor-made geopolymer binders for repairing historical stone structures and initially investigate the mechanical properties. In this context, firstly, the geopolymer binder mixtures were prepared at different ratios of metakaolin and Kutahya volcanic pozzolan while keeping the SiO_2/Al_2O_3, Na_2O/Al_2O_3, Na_2O/SiO_2 and H_2O/Na_2O proportions constant and the mechanical properties (compressive and flexural strength) of the geopolymer binders were evaluated. Secondly, based on the results, geopolymer mortar mixtures with a binder/aggregate ratio of 1:1 and 1:2 was prepared using natural limestone (Kufeki) powder as an aggregate, and their mechanical properties were evaluated. Moreover, since the future use of geopolymer in the restoration sector is significant, laboratory temperature was used for curing conditions (20±2 °C and 50±5 % relative humidity) in this study to simulate outdoor conditions. The compressive and flexural strength results are promising when compared to the technical specifications of certain ready-mixed stone repair mortars utilized in significant historical stone buildings abroad. This study indicates that metakaolin-natural volcanic pozzolan based geopolymer may be explored as a viable environmentally friendly alternative binder for stone repair mortars in future applications.

Keywords: Stone repair mortar, Geopolymer, Metakaolin, Natural volcanic pozzolan, Cultural Heritage

1. Introduction

Different types of natural stones have been used as traditional materials in historic monuments worldwide. Even though natural stones are known for their durability and longevity, they are susceptible to chemical weathering, physical degradation, and biological factors which mean that they cannot be classified as a truly inert material. Over time, this deterioration process especially affects architectural details exposed to external factors, causing cracks, surface loss and fragmentation of stone elements. Plastic repair techniques are used in conservation practices to eliminate such material losses and restore both the structural integrity and aesthetic value of historical stone monuments. This method is also known by various terms such as stone repair mortar, stone patch, surface fill and stone imitation (Válek et al., 2019; Isebaertet al., 2014;Ashurst & Ashurst, 1988). This method utilizes specially formulated mortars compatible with the original stone, that enable the reconstruction of missing or damaged areas and ensure the preservation of the monument's authenticity and durability (Válek et al., 2019).

Nowadays, two primary approaches are used in the design of plastic repair mortars for natural stones. The first approach is based on ready-mixed stone repair mortars, which are preferred for their ease of application and consistent quality. However, these products show significant limitations when selecting by users, such as lack of transparency regarding performance data, mortar composition information and non-standardized testing, as well as the inability to adapt to project-specific requirements (López-Arce et al., 2016; Lubelli et al., 2021; Török & Szemerey-Kiss, 2019).

Furthermore, differences in the manufacturing processes of products can cause significant performance differences between batches. As a result of this, concerns about the durability and consistency of repairs over time (Válek et al., 2019). A recent study on commercial repair mortars revealed different chemical and mechanical properties for each mortar compared to different substrates (Lubelli et al., 2021).

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The second approach involves designing custom stone repair mortars based on the characteristics of natural stones in order to create a composition that matches the original stone substrate as closely as possible (Isebaert et al., 2019). White cement is the most commonly used binder in many restoration projects for reconstructing missing stone parts due to its desirable color and relatively low sulphate and alkali contents (Papayianni, 2022; Papayianni et al., 2015; Stefanidou et al., 2015). Although cement-based mortars have good mechanical strength properties, their low deformability under large thermal cycles may be dangerous. This is because their high density and low porosity, coupled with high coefficients of thermal expansion, can impact natural stones (Quist et al., 2018; van Hees et al., 2002). Given the drawbacks of white cement, various environmentally friendly materials, such as geopolymers, have recently been investigated as binders in the preparation of repair mortars (Clausi et al., 2016; Van Roosmale et al., 2023). There are different types of geopolymers, which are inorganic, each with unique properties that can be modified by the accessible raw materials, aggregates and alkaline materials used (Cong & Cheng, 2021).

Initial studies on producing of geopolymers in heritage conservation have generally used metakaolin as a precursor (Clausi et al., 2016; Pagnotta et al., 2020; Ricciotti et al., 2017; Van Roosmale et al., 2023). In these studies, curing conditions at room temperature have been adopted to simulate outdoor environments during the development of geopolymer binders for stone repair in historical buildings because of its applicability (Clausi et al., 2016; Van Roosmale et al., 2023) However, many studies have investigated the possibility of the use of natural pozzolans to obtain geopolymers as an alternative to traditional cement (Bondar et al., 2010, 2011a, 2011b; Robayo-Salazar et al., 2016; Tchakoute et al., 2013).

On the other hand, their semi-crystalline nature constrains their effectiveness as the main precursor, particularly at room temperature (Robayo-Salazar et al., 2016; Tchakoute et al., 2013). For this reason, metakaolin is generally added to facilitate geopolymer formation and enhance reactivity under ambient conditions (Djobo et al., 2014; Robayo-Salazar et al., 2016; Tchakoute Kouamo et al., 2012).

Currently, there has been little or no research which focus on the combined the use of natural pozzolan and metakaolin materials in the field of stone conservation. Recognizing this gap, the aim of this study was to investigate whether such a combination could offer a viable solution for use in plastic repair of natural stone materials. In addition to this, the literature review highlights that the ratios of SiO_2/Al_2O_3, Na_2O/Al_2O_3, Na_2O/SiO_2, and H_2O/Na_2O, depending on the type of alkali activators used, significantly influence the mechanical properties of geopolymer binders (Davidovits, 1999; Ekiz Barış, 2022; Firdous et al., 2018; Palomo et al., 1999; Shi et al., 2006).

Therefore, firstly, these ratios were kept constant in geopolymer mixtures prepared with metakaolin and Kutahya volcanic pozzolan. The effect of varying metakaolin content on the compressive and flexural strength of the geopolymer binder system was examined under laboratory conditions (20 ± 2 °C and 50 ± 5% relative humidity) after both 7 and 28 days of curing. Based on the findings, secondly, geopolymer mortar mixes were produced using natural limestone (Kufeki) powder as aggregate, with binder-to-aggregate ratios of 1:1 and 1:2, and their mechanical properties were evaluated accordingly. Finally, the compressive and flexural strength results were compared with the technical specifications of certain commercial stone repair mortars commonly used in significant historic stone structures abroad.

2. Materials and methods

2.1. Materials

Kutahya volcanic pozzolan (NP) was first dried in a Memmert ventilated oven at 70 °C in order to remove its inherent moisture. Following this, the material was subjected to a series of grinding steps: initially in a RETSCH jaw crusher, then in a toothed mill to achieve particles below 1 mm, and finally in a ball mill for further refinement. Since particle fineness directly influences alkali activation reactivity, it contributes to improved mechanical strength (Firdous et al., 2018), appropriate sieving was performed. A review of the literature reveals that various studies on alkali-activated materials have employed different maximum particle sizes, including 90 μm (Ekiz Barış, 2022), 150 μm (Beghoura & Castro-Gomes, 2019), 200 μm (Tekin, 2016), and even up to 400 μm (Lemougna et al., 2011). In line with these findings, ground Kutahya volcanic pozzolan was sieved through a 150 μm mesh and subsequently stored in PE-coated containers to maintain its condition.

The metakaolin (MK) used as an artificial pozzolan in the mixtures was supplied by Kaolin Endüstriyel Mineralleri San. ve Tic. AŞ, located in Istanbul. The specific gravity of the metakaolin is 2.52 g/cm³. The combined content of silicon oxide (SiO_2), aluminium oxide (Al_2O_3), and iron oxide (Fe_2O_3) accounts for 97.18%, indicating a high pozzolanic activity. The chemical compositions of Kutahya volcanic pozzolan and metakaolin are presented in Table 1.

Table 1. Chemical composition of Kutahya Tuff and Metakaolin (%)

Material	SiO_2	Al_2O_3	Fe_2O	TiO_2	CaO	MgO	K_2O	Na_2O	Others	LOI
Kutahya tuff	72.57	11.67	1.39	0.06	1.07	1.07	5.92	1.03	0.27	4.95
Metakaolin	56.10	40.23	0.85	0.19	0.16	0.51	0.24	0.07	0.07	1.10

Sodium hydroxide (NaOH) was supplied by Kimyalab, while sodium silicate (Na_2SiO_3) was taken from ZAG Kimya LTD. The sodium hydroxide was provided in prill form with 99% purity, and potassium hydroxide was supplied in flake form with 90% purity. The Mod III sodium silicate solution, delivered in liquid form with 99% purity, had a molar ratio (SiO_2/Na_2O) of 2.74

Prior to the preparation of the solution mixtures, the NaOH was dissolved in deionized water and allowed to rest for 24 hours to ensure it was ready for use. In addition, natural limestone (Kufeki) powder sourced from Çatalca, Istanbul, was utilized as aggregate.

2.2 Mixture design

2.2.1 Geopolymer binders

For the synthesis of geopolymer binders, distilled water was added to the sodium silicate solution, which was then conditioned at 20 ± 2 °C and 50 ± 5% relative humidity for 24 hours. Following this period, solid sodium hydroxide was dissolved into the solution to modify its composition. Kutahya pozzolan was added to the prepared solution and mixed using a mortar mixer. The mixing process was carried out at a low speed (140 ± 5 rpm) for 60 seconds. Following this, water was incorporated and mixing continued at the same speed for an additional 60 seconds. The mixture was finally stirred at high speed (285 ± 10 rpm) for 180 seconds. After the mechanical mixing was completed, the remaining unmixed material manually mixed to the sides of the mixer was manually integrated so as to ensure homogeneity.

The fresh mortar was placed into molds (40 × 40 × 160 mm) and compacted by means of mechanical vibration for 60 seconds to eliminate trapped air bubbles. For each geopolymer binder formulation, three samples were prepared to ensure consistency and reliability in the tests. The fresh mixes were placed in molds that were covered with polyethylene (PE) sheets to prevent moisture loss and kept at 20 ± 2 °C and 50 ± 5% relative humidity for 2 days. After this initial period, the specimens were removed from the molds and allowed to cure under the same environmental conditions. The sample labels used for the synthesis, along with the constant ratios and corresponding water/solid ratios, are presented in Table 2. Furthermore, the production stages of the geopolymer binders are shown in Fig. 1 and the condition of the binder samples at the 7th day of curing is shown in Fig. 2.

Table 2. Details of geopolymer binders

Sample Code	NP (%)	MK (%)	SiO_2/Al_2O_3 (M)	Na_2O/Al_2O_3 (M)	Na_2O/SiO_2 (M)	H_2O/Na_2O (M)	Water/Solid Ratio
GP1	60	40	6.0	0.72	0.12	12	0.33
GP2	65	35	6.0	0.72	0.12	12	0.35
GP3	70	30	6.0	0.72	0.12	12	0.47

Fig. 1. Production stages of geopolymer binders

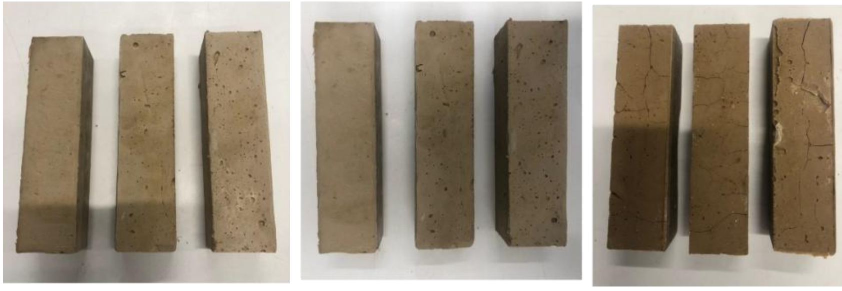

Fig. 2. The appearance of geopolymer binder samples on the 7th day of curing
(from left to right: GP1, GP2, GP3).

2.2.2 Geopolymer-based mortars

Geopolymer mortars with binder/aggregate ratios of 1:1 and 1:2 was prepared using geopolymer binders, respectively. Initially, the dry mixture of Kutahya pozzolan (sieved through 150 µm sieve diameter), metakaolin and aggregate was mixed for 5 minutes. This was followed by a gradual mixing process using a mortar mixer: the mixture was mixed at low speed (140 ± 5 rpm) for 60 seconds, then the activator solution was added and mixed at the same speed for another 60 seconds. Finally, the mixture was mixed at high speed (285 ± 10 rpm) for 180 seconds so as to ensure a homogeneous structure. This was followed by an additional 5 minutes of mixing with a mechanical hand mixer to further homogenize the mixture.

The fresh mortar was placed in molds (40 × 40 × 160 mm) and compacted by mechanical vibration for 60 seconds to remove trapped air bubbles. Three samples were prepared for each geopolymer binder formulation. To prevent moisture loss, the molds were covered with polyethylene (PE) sheeting and kept at 20 ± 2 °C and 50 ± 5% relative humidity for 2 days. After this period, the specimens were removed from the mold and left to cure under the same environmental conditions. The sample labels and proportions used for the synthesized geopolymer-based mortars are presented in Table 3, while the demolding and curing process of the NP+MK geopolymer mortar mixtures is illustrated in Fig. 3.

Table 3. Details of geopolymer-based mortars

Sample Code	NP (%)	MK (%)	Binder/Aggregate ratio	Water/Solid ratio
GP1-1	60	40	1/1	0.40
GP1-2	60	40	1/2	0.40
GP2-1	65	35	1/1	0.49
GP2-2	65	35	1/2	0.49
GP3-1	70	30	1/1	0.47
GP3-2	70	30	1/2	0.47

Fig. 3. Demolding and curing of NP+MK geopolymer mortar mixtures
(from left to right: GP1-1, GP2-1, GP3-1).

2.3 Test methods

Flexural tensile strength for each hardened geopolymer binder and mortar mixture was evaluated by means of three prismatic samples tested under the third-point loading method, in accordance with TS EN 1015-11. On the other hand, compressive strength was measured using six fragments obtained from the broken halves of these prisms after flexural testing (TS EN 1015-11, 2000). The reported values represent the average of three specimens for flexural strength and the average of six fragments for compressive strength.

3. Result and discussion

This study examined the compressive and flexural strength behavior of geopolymer binders and mortars which are formulated with different proportions of natural pozzolan (NP) and metakaolin (MK). Tests conducted at 7 and 28 days highlighted that, in addition to binder composition, the water-to-solid (W/S) ratio and binder-to-aggregate (B/A) ratio also had a meaningful impact on mechanical properties. Furthermore, in order to isolate the component effects on the mechanical properties, the SiO_2/Al_2O_3, Na_2O/Al_2O_3, Na_2O/SiO_2 and H_2O/Na_2O ratios were kept constant in all samples.

When examining the compressive strength data obtained from the GP1, GP2, and GP3 series samples (Fig. 4), it was observed that the highest compressive strength was achieved in the GP1-1 sample (Fig. 5), which contained 40% MK and had a water-to-solid (W/S) ratio of 0.40 (9.00 MPa at 28 days). This outcome can be attributed to the high soluble Al_2O_3 content of MK, which promotes the presence of a large amount of amorphous aluminosilicates within the system. As previously reported in the literature (Tchakoute Kouamo et al., 2012, 2013), the addition of MK creates a more favorable environment for geopolymerization, unlike NP, which has a semi-crystalline structure. Having a better understand about these kinds of microstructural developments will be possible via a comprehensive examination of the geopolymer binder's microstructure.

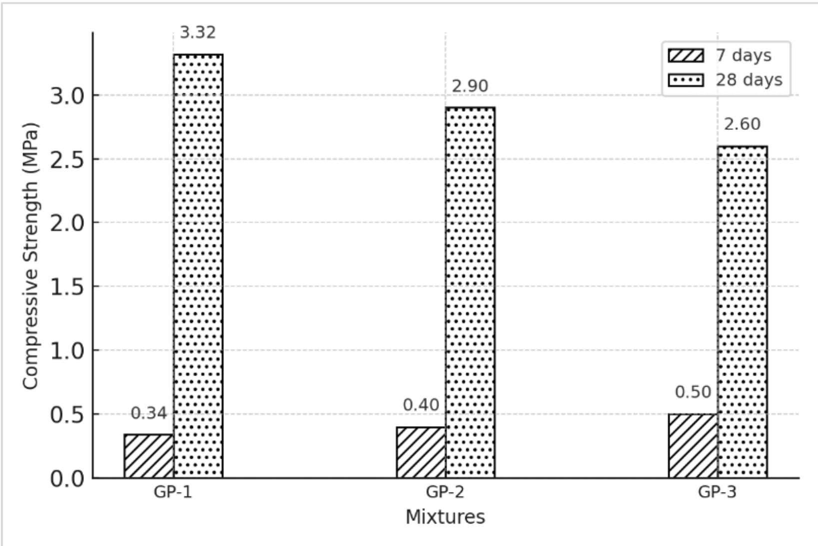

Fig. 4. Compressive strength of geopolymer binder mixtures

Fig. 5. The appearance of geopolymer mortar samples on the 28th day of curing (from left to right: GP1-1, GP2-1, GP3-1).

In the GP1-2 and GP2-2 samples, in which the binder-to-aggregate ratio was increased to 1/2, a significant decrease in compressive strength was recorded (Fig. 6). In particular, the 28-day strength of the GP2-2 and GP3-

2 samples (Fig. 7) were measured at 4.77 MPa and 2.05 MPa, respectively. This reduction can be explained by the lower amount of binder and the decreased water retention capacity within the matrix. Furthermore, efflorescence observed in the GP3-2 sample (Fig. 7) — formed by the crystallization of excess sodium ions through carbonation on the surface— negatively affected the strength (Vickers et al., 2015).

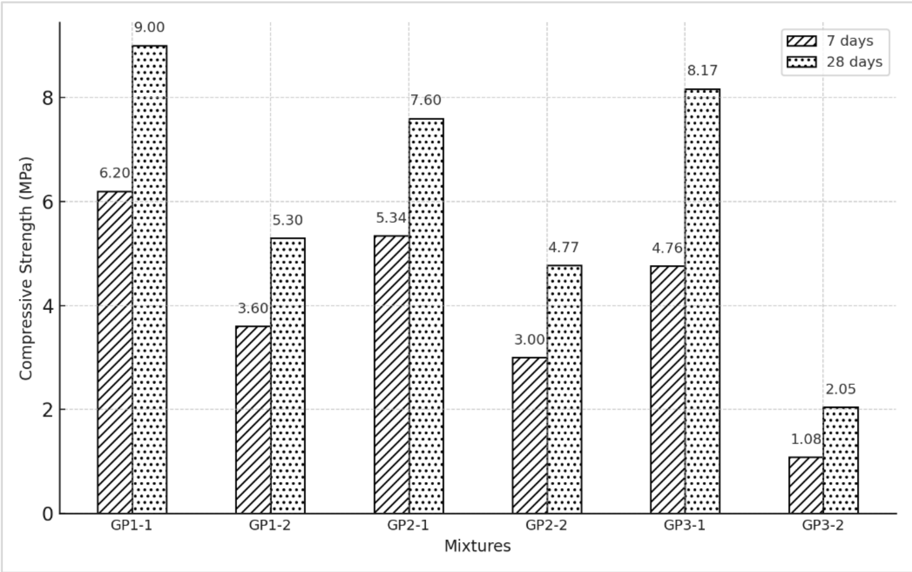

Fig. 6. Compressive strength of geopolymer mortar mixtures

Fig. 7. The appearance of geopolymer mortar samples on the 28th day of curing
(from left to right: GP1-2, GP2-2, GP3-2).

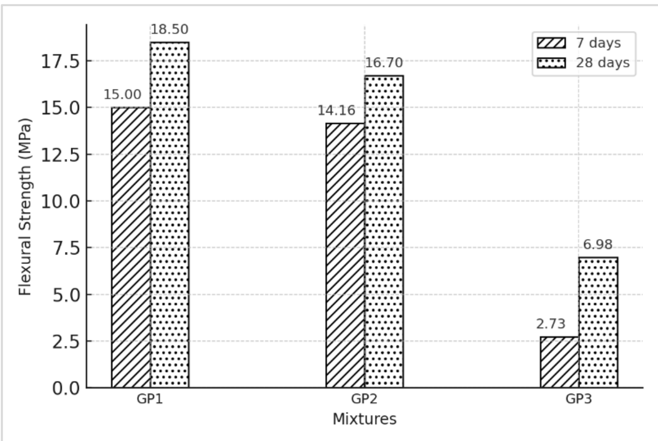

Fig. 8. Flexural strength of geopolymer binder mixtures

Flexural strength results followed a similar trend (Fig. 8 and Fig. 9). GP1-1 led with a value of 4.00 MPa at 28 days, reinforcing the benefits of high MK content and a lower water ratio (Fig. 9). A tightly bonded matrix may helps resist microcracking and enhances flexural performance.

On the other hand, the GP3-2 mixture, which had the lowest MK content (30%) and the highest water content (0.47), showed a compressive strength of just 1.29 Mpa (Fig. 9). The excessive amount of water likely interfered with gel formation, inducing a more porous and fragile structure (Clausi et al., 2016).

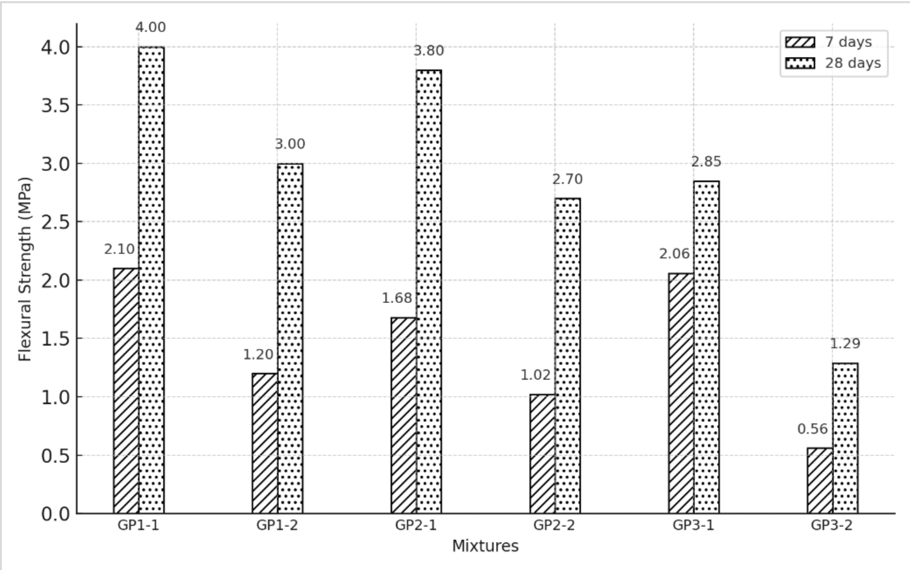

Fig. 9. Flexural strength of geopolymer mortar mixtures

The curing conditions used in the experiments to simulate ambient environmental conditions were set at 20 ± 2 °C and 50 ± 5% relative humidity (RH). However, this represents a lower humidity environment compared to the reported some values in the literature, such as 90% RH. This may have reduced the mechanical strength by means of slowing down the formation of aluminosilicate gel (Clausi et al., 2016; Robayo-Salazar et al., 2016). Moreover, the use of higher water content in some mixtures may have further intensified this effect and limited the strength development.

The mechanical performance of the developed geopolymer mortars was compared with that of several widely used commercial stone repair products, as summarized in Table 4. Among all tested mixtures, GP1-1 stood out with a compressive strength of 9.00 MPa and a flexural strength of 4.00 MPa at 28 days, outperforming all commercial references in terms of flexural behavior. Similarly, GP3-1 achieved strength values to some products, such as Jahn M70 and Bridevaux mortars.

It is important to note that these strength levels were reached under ambient curing conditions with relatively low humidity, without the need for heat condition or specialized environments. This highlights the potential of pozzolan and metakaolin-based binders according to their ratios as a sustainable and practical alternative to traditional cement-based restoration mortars.

Table 4. Compressive and Flexural Strength Comparison with Composition

Sample Code	Compressive Strength (28d) [MPa]	Flexural Strength (28d) [MPa]	Composition
GP1-1	9.00	4.00	NP 60% + MK 40%
GP1-2	5.30	3.00	NP 60% + MK 40%
GP2-1	7.60	3.80	NP 65% + MK 35%
GP2-2	4.77	2.70	NP 65% + MK 35%
GP3-1	8.17	2.85	NP 70% + MK 30%
GP3-2	2.05	1.29	NP 70% + MK 30%

Table 4 continued

Jahn M70	17.0-22.0	3.7-4.2	Mineral-based (URL-1)
Lithomex	7	-	Natural hydraulic lime, aggregates (URL-2)
Restoration Mortar ZF (Remmers)	8	5	Mineral-based (URL-3)
Artar Pierre	13	2.7	quartz aggregate, hydraulic binders, admixtures, and mineral pigments (URL-4)
Artopierre TF	2.4	1.3	Air lime + hydraulic lime, siliceous sands, organic additives, mineral pigments (URL-5)
Bridevaux	8.0-11.0	2.1-4.0	Mineral-based; lime, trass, white cement, additives (URL-6)

4. Conclusion

This research investigated how variations in NP/MK content, binder/aggregate ratio, and water/solid ratio affect the mechanical properties of geopolymer binders and mortars. Based on the experimental findings, the following conclusions can be drawn:

- Increasing the metakaolin content to 40% and lowering the water/solid ratio to 0.40 had a positive effect on both compressive and flexural strength.
- The 1:1 binder/aggregate ratio provided more consistent strength improvement than 1:2 mixes.
- The GP1-1 formulation offered the highest performance across all evaluated parameters due to its balanced design.
- The visible efflorescence showed that the importance of appropriate alkali ratio in order to provide mechanical stability and surface quality.
- The curing conditions used in this study were enough for comparative purposes, but likely limited for maximizing strength potential especially in NP-rich systems.

Moreover, when compared to many commercial stone repair mortars, the GP1-1 and GP3-1 formulations achieved compressive and flexural strength values within a competitive range. In particular, GP1-1 exceeded the flexural performance of all reviewed commercial products, which demonstrates its potential for use in restoration applications where crack resistance and cohesion are critical.

Overall, geopolymer mortars designed with high ratio of MK, lower water content and improved curing conditions represent a promising alternative to conventional cementitious binders. These systems demostrate strong potential for sustainable construction applications and may offer certain advantages in restoration or conservation works which durability and environmental compatibility are important.

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Investigation of windows of traditional houses in Duzce-Prusias region

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Abstract. Turkey's rich cultural past has hosted many different civilizations throughout history, and this has shaped the country's rich cultural heritage. This diversity is not limited only to art, literature and music, but also makes itself felt strongly in the architecture of traditional Turkish houses. Traditional Turkish houses have a unique architectural structure shaped in line with local climatic conditions, social structure and cultural climates. Building elements also bear important traces in this original architecture.

This study involves examining the windows of traditional Turkish houses in the Prusias region of Düzce province. In the study, as a result of the analyzes made on three different buildings selected from the historical neighborhoods in the Prusias region, the condition of the windows of these buildings was discussed in detail. Through the studies carried out on traditional buildings, the functional features of the windows, their dimensions, wing opening directions, material properties, number of horizontal and vertical partitions, ornamentation and decoration details were examined. Window models were created by taking window surveys of each building and these window models were documented by taking photographs. As a result of the research, the unique structural and aesthetic features of the windows of traditional houses in the Prusias region were revealed; It was concluded that the windows should be repaired and protected. In this way, the window designs and aesthetic features of our traditional buildings have been left as a legacy to future generations.

Keywords: Düzce-Prusias Region, Traditional Turkish House, Window.

1. Introduction:

Turkey's cultural past is clearly evident in the unique architectural features of traditional Turkish houses. The Turkish house is an important type in world architecture literature, the most striking basic elements in the facade designs of these houses are the unique arrangements in the window rows and the distinct proportions on the facade surface. This rhythmic order that forms the facade offers a flexible analysis based on traditional measurements and proportions. Especially the window spaces and arrangements on the wall surfaces are not only a formal approach, but also a form of expression that bears the traces of a cultural and social lifestyle. In this context, the facade design of the Turkish house is seen as the architectural features of a traditional philosophy of life and cultural identity (Yüksek, 2004) .

For centuries, the purpose of benefiting from daylight has become an important factor in building design (Yener, 2008). Window joinery serves the function of illuminating and ventilating the interior of spaces in traditional Turkish houses. Openable and closed window sashes provide coolness in the summer months and contribute to the preservation of interior heat in the winter months. The layout and features of the equipment elements are planned according to ergonomic principles such as efficiency of use, order of use and storage. Fixed equipment in Turkish houses are the basic elements that provide functional shaping of the space. External factors in traditional Turkish houses, factors such as land structure, street and landscape relationship play a role in the distribution pattern. Similarly, the opening directions, proportions and dimensions of the windows are also affected by these factors. It is observed that especially the dimensions on the facades facing the landscape or the garden are larger and windows are used more frequently (Sakal & Kahraman, 2020). .

Traditional Turkish houses in different regions of Türkiye have their own unique structural features. In the architectural design of these houses, the window joinery among the façade elements also has a distinct originality. The preservation of the window joinery is important in terms of transferring these cultural formations to future generations.

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1.1. Purpose:
The history of Düzce province, located in the Western Black Sea Region, dates back to the Hittite civilization that reigned between 1390-800 BC. In the historical process, Düzce has been under the influence of various tribes and states and today, people with different cultural identities live together (Kaya, 2023). Within the borders of Düzce province, there are important archaeological and architectural remains such as the Prusias region ancient theater, aqueducts, city walls and examples of traditional civil architecture. Düzce was separated from Bolu province and became a province on December 9, 1999.

The aim of this study is to examine the window joineries with unique architectural and structural features of traditional Turkish houses located in different regions of Anatolia in the Prusias region of Düzce province and to evaluate the usage characteristics, material properties and geometric appearances of the window models specific to the region.

1.2. Method:
For the purpose of this study: Traditional Turkish houses in the Prusias region within the borders of Düzce province were selected as the study area. These houses were divided into regions on the map and each was named and the window elements were examined in detail. The dimensions of the window elements were measured and damaged and divided sections were identified. The functional properties of the window models, the construction materials used and the usage details of these materials were investigated in detail and the work process was documented by taking photographs of the windows. Drawings of the window models were taken and drawings were produced in digital environments using the survey drawings and window models were extracted.

2. Information About Traditional Turkish House Windows:
Space comes into existence thanks to light. Light is among the important parts of structures surrounded by walls. Humans have opened gaps at certain intervals in order to provide light and air access to the space part that is limited by walls by separating it from its natural environment, protecting it and covering it. Windows are the most obvious example of these interventions and gaps (Uluengin,1982). Windows are elements located on the outer shells or inner walls of structures and undertake important functions. While these elements fulfill basic tasks such as air circulation, establishing visual relations and creating connections between spaces; they also undertake functions such as lighting, security and control (Bulut, 2001). The use of window elements at different intervals and periods creates an important effect on people who are deeply attached to geometric and numerical data. Along with the rhythmic effect of the gap order, the surrounding, decoration and ornamentation of this space, the material, color and texture of the building surface and structural elements offer endless variety in this area. From the beginning of the void to the present day, every civilization has handled and processed these elements in a unique manner, reflecting its cultural identity (Uluengin,1982).

2.1. Traditional Turkish House Window Types:

2.1.1. Vertical Sliding Windows (Guillotine):
The guillotine window is a type of window commonly used in Ottoman and Turkish architecture. There are different types of this window, single-wing and double-wing (one fixed, the others movable or both wings movable), and these types are the most frequently used models (Demirkan, 2023). Guillotine windows contain two glass panels. These panels move between the slats located on the sides. They generally move up and down. This design allows the panels of the window to move independently (Fig. 1).

Fig. 1. Guillotine Window Example

2.1.2. Double Casement Window:
Double-winged window systems are generally a type of window consisting of two sashes, each of which can be opened separately. This system allows for more efficient air performance. The ability to open the sashes independently enables effective ventilation of the space. Double-winged windows usually have large glass panel surfaces, which allows more light to enter the interior (Fig. 2) (Sakal & Kahraman, 2020).

Fig. 2. Double Casement Window

2.1.3. Skylights:
Skylights are types of windows that are opened to the dome drums and skirts of domes, especially in Anatolian Turkish Architecture, in order to allow natural light into interior spaces, and are closed with fixed plaster workmanship (Sağiroğlu Arslan, 2014) . This window placement is designed to provide maximum light and ventilation and is usually located in high positions. Although the form dimensions of skylights are rectangular or square, they can also be created in different geometric structures depending on the local architectural structure and design preferences. They are usually made fixed because they are at a height that people cannot reach and do not need to be opened (Sakal & Kahraman, 2020). .

2.1.4. Concentric Window:
A type of window created in the 19th century by designing two windows in a row to provide heat and sound insulation. It was usually made in rectangular and elliptical shapes. The construction material used was wood (Çelik, 2025a) .

2.2. Traditional Turkish House Window Elements:

2.2.1. Lintel:
Small stone, concrete or wooden beams placed on the upper part of these forms and sitting on the side walls in order to carry the wall loads on the window edges are also called "lintels". Lintels are fastening elements placed on the upper part of the jambs or window openings and transmit the loads coming from the top to the side walls, allowing for wide window options (Sağiroğlu Arslan, 2014) .

2.2.2. Jamb:
Jambs are vertical frame elements placed on both sides of window and door openings. They are made of stone or wooden materials. They are placed on both sides of the door and window frame as a post element. Jambs consist of sections such as the post post (window post), the post sill and the post stone (Sağiroğlu Arslan, 2014) .

2.2.3. Telaro:
Telaro is the fixed section that connects the window to the wall. In openable windows, the window sash is mounted to the telaro by means of a hinge. The hinge is a metal support element used to ensure the movement of the sash and to transfer load to the telaro separated from the sash. The mounting method of the hinge determines the opening direction of the sash (Bulut, 2001).

2.2.4. Sill:
The sill is a structural element used to cover the junction of the window sill with the wall plaster. It is located on both sides and the upper part of the window. In double-skinned windows, this element, which forms a slot for the sash together with the frame during the transportation of the inner sash, is also used to ensure the aesthetic integrity of the interior space (Bulut, 2001).

2.2.5. Wing:
The movable carrier connected to the telaro by a hinge is defined as 'wing'. In window joinery, the telaro-wing joint is designed in the joint area between the sash and the telaro to prevent the passage of unwanted elements such as air, water, and dust into the interior. When the sash is closed, the recess (lamb) and protrusion (tenon) connection elements that are compatible and have complementary features on the sash and telaro surfaces in order to ensure the sealing of the joint between them are called 'bini' (Bulut, 2001).

3. Field Study:

3.1 Düzce Prusias Region:
Prusias region of Düzce province in the Western Black Sea Region is a settlement area located at an altitude of approximately 200 meters in the northeast of Düzce Plain. Prusias region borders Zonguldak and Bolu provinces to the east and Sakarya province to the west. Düzce province is bordered by the Black Sea to the north (Fig. 3) (Sabuncu, 2022).

Fig. 3. Duzce Province Map (Çelik, 2025b)

The location of Düzce, especially its proximity to major metropolitan cities such as Ankara and Istanbul, directly affects the economic situation of the province. This easily accessible location provides the opportunity for Düzce to become an important trade and industrial center thanks to its easy access to economic activities. In this context, in the sectoral evaluations made, it is observed that Düzce has a rapidly developing structure in the industrial field (Besli, 2019).

The study area is a Bithynian city known as Prusias ad Hypium, located 8 km north of Düzce province, in the middle of Ankara and Istanbul. The settlement was built on a hill in the middle of the Little Melen Stream (Hypios). This hill stands out as a part of the mountain range (Bilir, 2013). The city, which remained under the sovereignty of the city of Herakleia Pontica for a long time since its foundation, was added to the borders of the Kingdom of Bithynia together with the city of Tios by the King of Bithynia Prusias I. It was named Prusias ad Hypium, meaning Prusias near the Hypios (today's Melen) River. The city, which has been inhabited continuously since its foundation, was included in the Ottoman lands by Prusias Gazi, one of the margraves of Osman Bey, in 1323. Its name in the Ottoman Period was Üskübü. It was later named Prusias and has remained with this name to the present day (Okan, Bilir & Çalişkan, 2022). The settlement was divided into I, II and III degree archaeological sites by the Kocaeli Cultural Heritage Preservation Board with the decision numbered 894 dated 20.03.2013. Houses, city walls, Roman bridges, aqueducts and theatre were registered as sites (Naldan, 2019).

3.2 Characteristics of Traditional Houses in Prusias Region:
The traditional building culture seen in the Prusias Region is the wood frame (infilled with bricks in between) system. It forms the carrier system of a skeleton structure consisting of columns and beams. The wood frame skeleton system used in traditional local houses is built on stone foundation walls. The spaces between this wood frame skeleton system are filled with stone, adobe, wood or brick. This system is generally called 'hımı'. These walls are then plastered and the system is completed. In some houses, the walls are left without plastering. Thus, a structure as light as possible is obtained. The ground floor of the Prusias traditional house, which is generally designed as 1 or 2 floors and rarely as 3 floors, is mostly allocated for uses such as barn, hayloft, service units and kitchen, while the main living floor of the house has always been the first floor. The roofs, which also have a sloping wooden system, are generally covered with Marseille tiles and rarely with Turkish style tiles. The historical housing texture in the region is mostly composed of wooden frame houses with brick fillings connected with lime mortar (Fig. 4) (Tanriverdi Kaya, Demir & Ayengin, 2017).

Fig. 4. Housing Texture Example

One of the most important visual effects in the façade arrangement is the windows. The size and width of the windows vary according to the façade of the house; there are fewer windows on the lower floors and more on the upper floors. The width and height measurements of the windows are made in various sizes and dimensions in order to maintain the rectangular form. At this point, it is observed that guillotine and casement type wooden joinery windows are preferred (Naldan, 2019).

4. Results and Discussion:

In this study, the models, functions, horizontal and vertical axis positions, dimensions, material types and connection details of the windows in three different structures selected from the Düzce-Prusias region were determined. The structures were categorized as İşler Evi, Terzialiler Evi and Kaleler Evi according to their locations.

4.1 İşler House Windows:

The building is located on Çarşıiçi Street and is within the second degree archaeological site. The three-storey building consists of a ground floor, first floor and second floor. The ground floor is used for commercial purposes and there is a shop here. The door and window elements of the building are damaged and some are completely dysfunctional. All door and window joinery is made of wood. The floor of the building is built with solid rubble stones and the upper floors have a wooden cracked brick wall system. In this system, the building loads are transferred to the ground via wooden studs and beams positioned within the wall. The section dimensions of the wooden upright elements used in this structure with a traditional wooden system were selected as 10 cm on average. The ground floor consists of two rooms and an entrance hall. The floor plans of the structure are designed in accordance with the interior sofa plan type. There are uprights called "shoulders" on the edges of the windows on the first and second floors. In addition, there is a large fixed window on the upper part of the entrance door, and thanks to this window, the entrance hall and the staircase section are illuminated with natural light (Fig. 5).

Fig. 5. İŞLER House Facade Photos

Six types of windows have been determined in İşler House according to their sizes. These windows İH-W1 (126x115 cm), İH-W2 [151x118 cm), İH-W3 (89x145 cm), İH-W4 (167x130 cm), İH-W5 (127x130 cm) ve İH-W6 (137x131 cm)'dir. The appearance of the windows is given in Fig. 6.

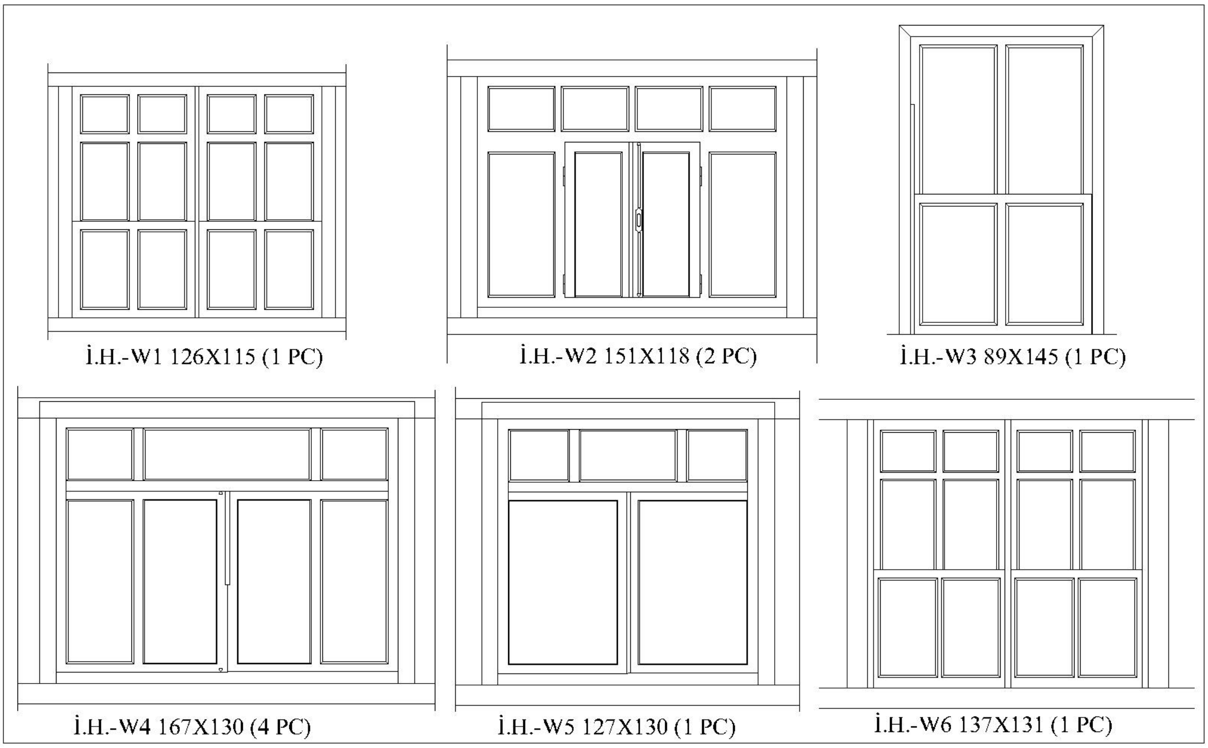

Fig. 6. İŞLER House Window Views

4.1.1. İ.H.-W1(126 x 115 cm):

The P1 opening window in İşler Evi is a two-pane guillotine type model and is located on the second floor of the building. The window is placed on the inside of the wooden frame wall. The frame-wing and wing-wing joints are designed in a flat manner. In order to ensure the stability of the fixed wing, the lower part is supported with slats. The openable wings are supported from the inside with fixed wings and a flat slat on the top and from the outside with a slat fixed to the sill. The openable wings move up and down between these slats. The connection of the window frame to the wall is provided by connecting to fixed wooden studs. The window wings have a sliding system that moves vertically. The dimensions of the window are 126 cm x 115 cm. The window joinery is divided into three rows horizontally and four rows vertically (Fig. 7 and Fig. 8).

Fig. 7. İ.H.-W1 Window View

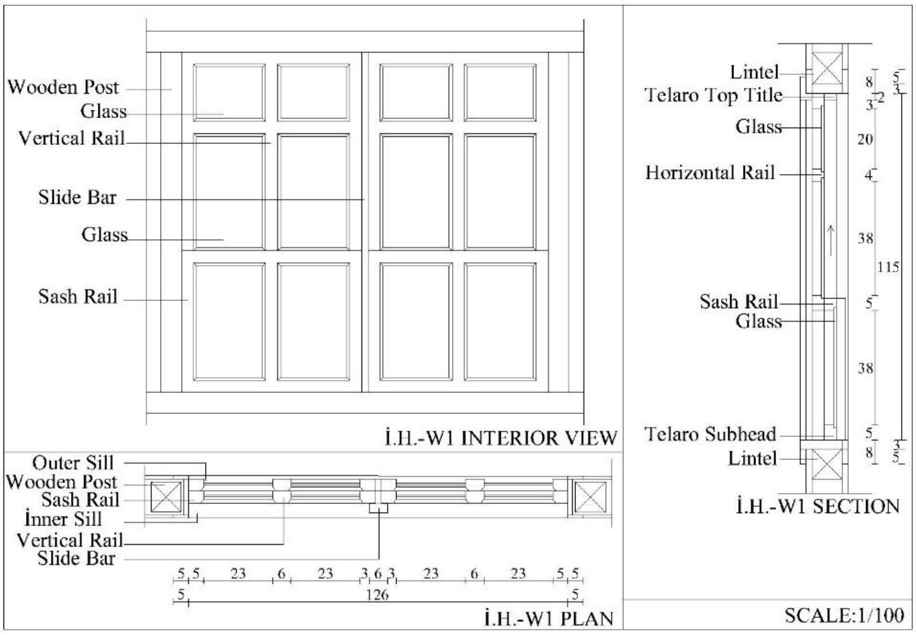

Fig. 8. İ.H.-W1 Detail Drawing

4.1.2. İ.H.-W2 (151 x 115 cm):

The window on the inside of the wooden frame wall, the frame-wing and wing-wing joints are designed according to the lamp detail. The upper part of the window is fixed and divided into four equal sections with vertical cuts. There are two openable wing windows positioned at the bottom, and there are two fixed windows on the sides. The joinery is painted in white. The internal locking of the windows is designed according to the period and integrated on the wing. The locking system of the window, The locking system moves up and down by working with the metal arm on the wing, this metal bar enters the slots inside the openings on the upper and lower parts and provides locking opportunity. There is no metal railing on the window in question. The window is designed to open horizontally and rotatably towards the interior. Since the wings can be opened inwards, the hinges are mounted on the inside of the window. The dimensions of the windows are 151 cm x 115 cm, and the divisions are designed to be three sections horizontally and four sections vertically (Fig. 9 and Fig. 10).

Fig. 9. İ.H.-W2 Window View

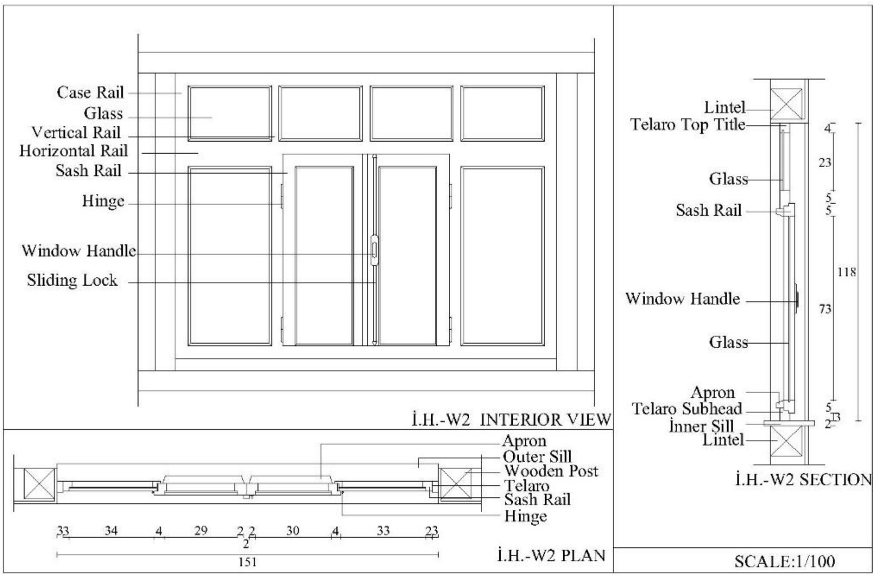

Fig. 10. İ.H.-W2 Detail Drawing

4.2 Terzialiler House Windows:

Terzialiler House is located next to the historical Roman Bridge. The three-story structure is designed as a basement, ground floor and first floor. The construction technique is based on the principle of wooden material placed inside with frames. The outer walls are covered with Baghdadi plaster, while the inner walls are covered with plaster selected as "malis" and made of water, soil and straw. The foundation of the building is built of rubble stones. In addition, wooden beams are placed between the rubble stone walls to ensure their integrity. All of the doors and windows in the structure are made of wood. In terms of spatial organization, the rooms are built to be on the sides of the sofa. The windows on the ground floor are wooden with wings, and on the first floor there are two and three-pane guillotine type windows. On both sides of the door entrance, sliding guillotine windows were placed to provide light to the hall. Vertical and horizontal lines were used around the room windows. On the first floor, a bay window was made to project outwards from the hall. There are two guillotine type windows on the front facade of the bay window and one on each side facade. The bay window in question added movement to the facade design. Some doors and windows in the building were deformed (Fig. 11).

Fig. 11. TERZİALİLER House Facade Photo

Five types of windows were determined in the Terzialiler house according to their sizes. These windows are TH-W1 (68x140 cm), TH-W2 (46x99 cm), TH-W3 (47x87 cm), TH-W4 (157x128 cm) and TH-W5 (210x130 cm). The appearances of the windows are given in Fig. 12.

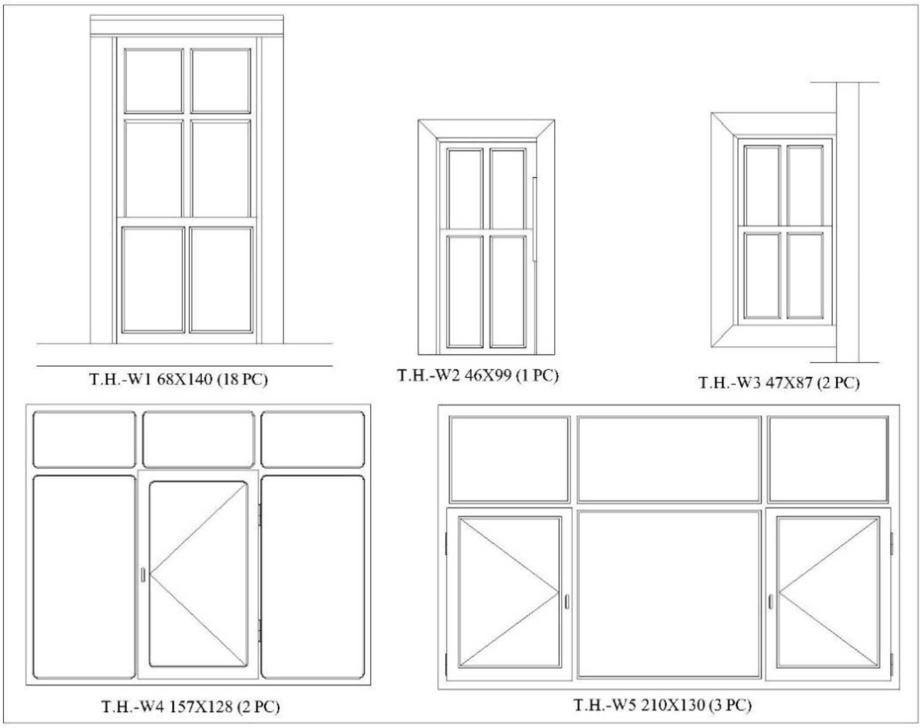

Fig. 12. TERZİALİLER House Window Views

4.2.1. T.H.-W1 (68 x 140 cm):
The windows located on the ground and first floors of the building have a single-pane guillotine type window model and are placed on the inside of the wooden frame wall. The windows in question are placed on horizontal joists, and the frame-wing and wing-wing joints are designed in a flat form. The opening wings are supported from the inside with fixed wings on top, a flat lath on the bottom, and a lath fixed on the joist from the outside. Thanks to this mechanism, the opening wings can move up and down so that they remain between the laths. When the windows are placed directly on the joists, no sill is made on the window. There is no locking system or railing in the parts of the structure. The window opening wings are vertical sliding. There is a fixed wing in the upper section and a movable wing in the lower row. The dimensions of the windows are 68 cm wide and 140 cm long. There are a total of 18 windows of the same series in the structure. The window joinery is designed to have three sections horizontally and two sections vertically (Fig. 13).

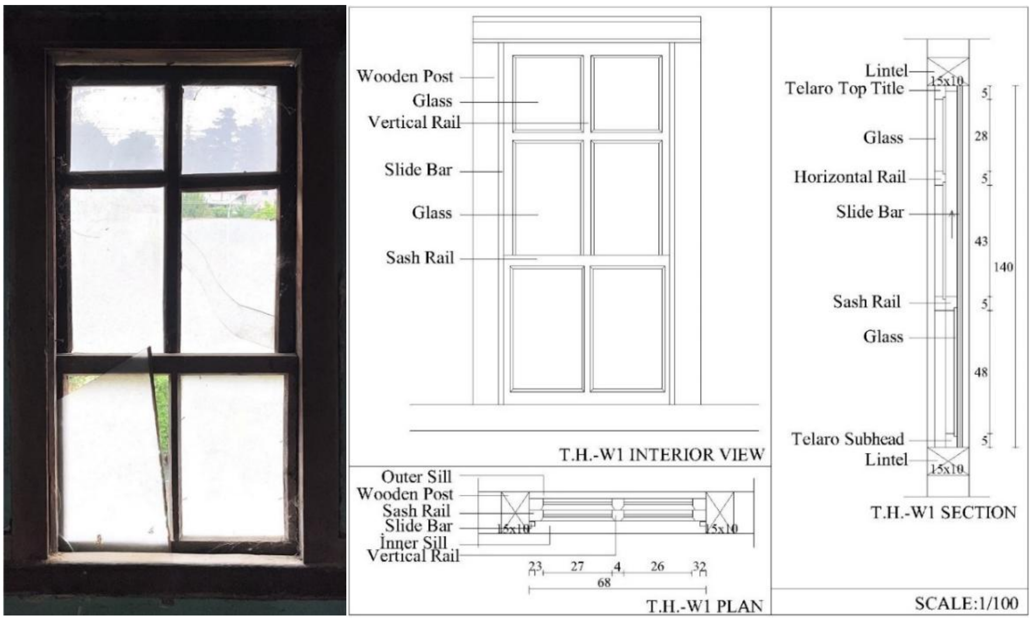

Fig. 13. TH-W1 View And Detail Drawing

4.2.2. T.H.-W4 (157 x 128 cm):

The window, positioned on the inside of the wooden frame wall, has the details of a frame-wing with lamp and a wing-wing with lamp. The upper section of the window is fixed and divided into three sections with vertical slats. In the lower section, there are two fixed windows on the edges and an openable wing window in the middle. The joints at the junction points of the window frame with the wall are covered with plaster on the inner and outer surfaces and painted. There is a locking system in the interior of the windows. The window is locked by turning the tongue of the metal window handle. No metal railing is used in the window design. The window is designed to rotate towards the interior. Since the window wings open inwards, the hinges are arranged to be located in the interior. The window dimensions are 157 cm x 128 cm. The divisions in the window joinery consist of two sections horizontally and three sections vertically (Fig. 14 and Fig. 15).

Fig. 14. TH-W4 Window View

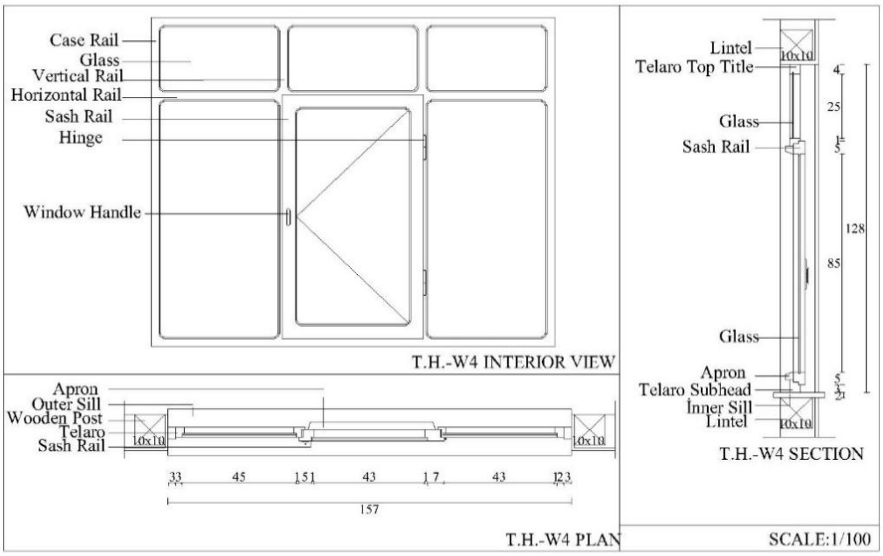

Fig. 15. TH-W4 Detail Drawing

4.3 Kaleler House Windows

Kaleler Evi is located right next to the ancient theater. The building has three floors: basement, ground floor and first floor. The construction system of the house consists of brick material filled into a wooden frame. The exterior and interior walls of the building are covered with traditional Baghdadi plaster and painted. The foundation of the building is made of rubble stones. All doors and windows of the building are built using wood. The rooms are designed to be on the sides of the sofa. Guillotine type windows were preferred as the window model. Both vertical and horizontal girders were used on the edges of the room windows. Some windows in the building are deformed (Fig. 16).

Fig. 16. KALELER House Facade Photo

Three types of windows were determined in the Kaleler house according to their sizes. These windows are KH-W1 (68x140 cm), KH-W2 (46x99 cm) and KH-W3 (47x87 cm). The appearances of the windows are given in Fig. 17.

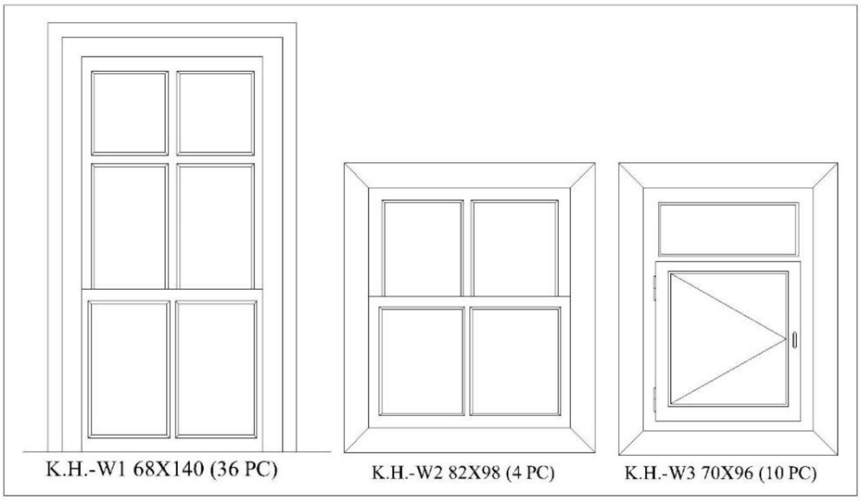

Fig. 17. KALELER House Window Views

4.3.1. K.H.-W1 (68 x 140 cm):

The window is located on the inside of the wooden frame wall and has a single-pane guillotine type window model. This window is located on the ground and first floors of the building. The windows in the building are placed on horizontal joists and supported by joists around them. The frame-wing and sash-wing combination is designed in a flat manner. The opening wings operate with a vertical sliding movement. While there is a fixed wing in the upper section, there is a movable wing that opens upwards in the lower row. The opening wings are supported by a fixed wing and a flat lath on the top and are strengthened with a lath fixed to the upper level of the sill on the outside. The wings can move up and down by remaining between the slats. The window is surrounded by sills on the outer and inner surfaces. The window, which is painted in brown tones, does not have any locking system or railing. The window dimensions are 68 cm x 140 cm and there are a total of 36 identical model windows in the structure. The sections in the window joinery form three horizontal and two vertical series (Fig. 18).

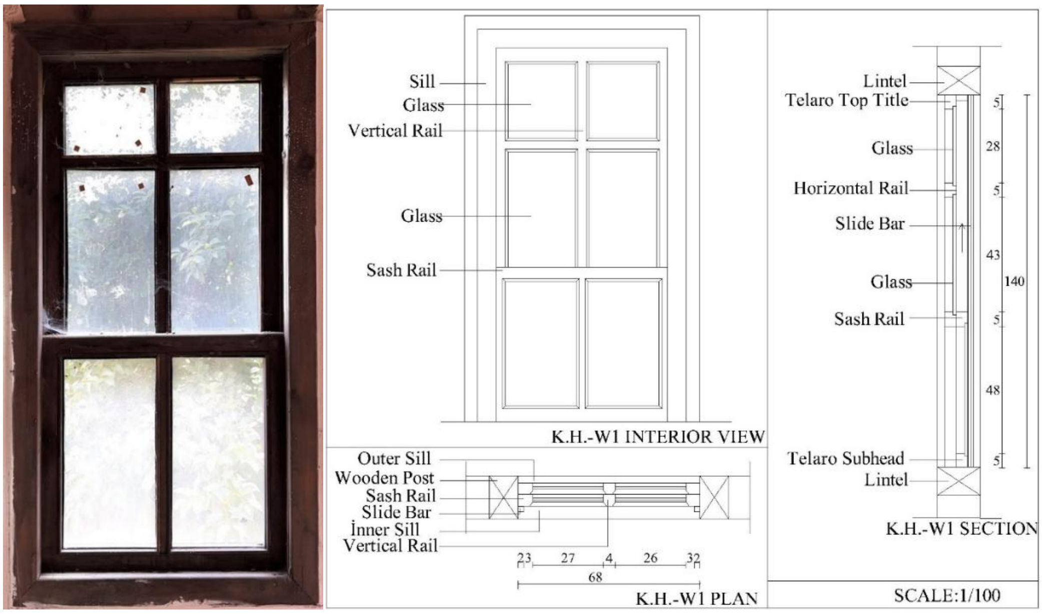

Fig. 18. KH-W1 View And Detail Drawing

4.3.2. K.H.-W2 (83 x 98 cm):
The window is located on the inside of the wooden frame wall and is designed in a single-pane guillotine type model. The frame and sash combination and the sash-sash combination are made in a flat manner. The opening wings move vertically, there is a fixed sash on the top, and there are upward-moving wings on the bottom. The opening wings are supported by the fixed wings on the inside, and the upper part of the sill is supported by a fixed slat on the outside. The opening wings can move up and down between the slats. The window is coated with brown paint. The window dimensions are 83 x 98 cm, and there are two horizontal and two vertical series of panes. There are a total of 4 identical model windows in the structure (Fig. 19).

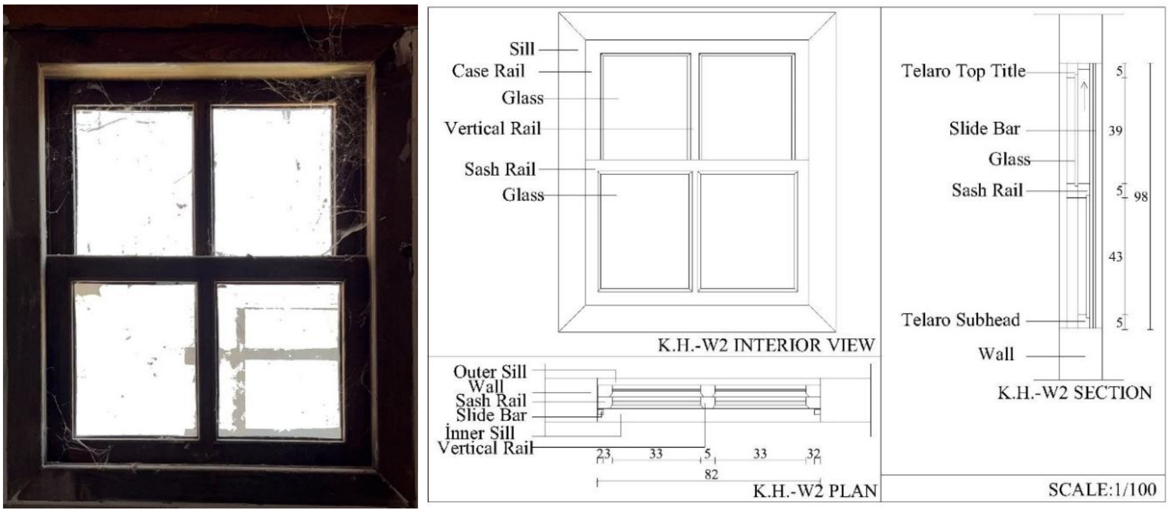

Fig. 19. KH-W2 View And Detail Drawing

5. Conclusions
Analyses conducted on traditional houses in Düzce reveal that some houses have begun to lose their original characteristics. This situation necessitates taking various protection measures in order to prevent the disruption of the continuity of these structures with historical value. The carrier systems of the houses generally consist of wooden frame material, but various materials have been used as fillings between the wooden frames. These materials are generally observed as brick, adobe filling or wooden slats.

The window frames are made entirely of wood, considering the intense climate conditions and abundant forest areas. The frames are placed on the inside of the wall, the inner frame is placed in accordance with the depth of the wall with wooden cladding and supported with wooden frame material from the outside. These frames form the window frame together with the wooden sill located at the bottom. The wings and sometimes the drips on the frames are designed with horizontal records. There is no fixed strut between the wings. The window sections successfully reflect the square record and rectangular texture samples frequently seen in traditional Turkish houses. The wings are divided by elegant slats and contain different outdoor perspectives. The case and records are generally made in similar dimensions. In addition, the wall junction of the case is covered with wooden cladding or slats to protect against leaks. In double-winged windows, special locking gaps are designed with a remarkable system by being integrated into the lower or upper sash. Some double-winged windows open by turning sideways outwards, so the hinges are made on the outside. This system is different from today's.

Various regions of our country have a rich history with unique architectural structures. However, due to the conditions in our country, there are some deficiencies in the preservation of these architectural heritages. This research aims to contribute to the transfer of this information to future generations by examining the construction and technical features of the windows in our traditional buildings.

Acknowledgments
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Seismic assessment and effectiveness of structural retrofitting techniques: A case study of industrial chimneys at Khosravi Leather Factory in Tabriz

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Abstract. The Khosravi Leather Factory in Tabriz is historically significant as a key example of Iran's early industrial era. Following its renovation and transformation into part of the Islamic Art University of Tabriz, the factory building has become an essential component of the university campus. This study focuses on the dynamic behavior of the industrial chimneys within this complex, which are tall and slender structures that are vulnerable to seismic forces.
The previously implemented seismic retrofitting technique involved installing metal rings around the chimneys, and this technique is thoroughly examined in this study. Output-only dynamic testing was conducted to investigate the behavior and effectiveness of the retrofitting method. The tests were performed twice: first with the rings in place and then after their removal to eliminate any residual pressure effects.
The test results, along with the observed changes in frequency, demonstrate that this retrofitting technique did not achieve the intended improvement in structural performance. This article provides valuable insights into the seismic assessment of industrial chimneys and critically evaluates the effectiveness of retrofitting techniques, using the Khosravi Leather Factory as a key case study.

Keywords: Seismic assessment; Structural retrofitting techniques; Industrial chimneys; Khosravi Leather Factory; Dynamic testing.

1. Introduction

The preservation and enhancement of seismic performance in historical and industrial structures have gained significant attention in the fields of engineering and architectural restoration. Ensuring the structural integrity of these buildings while aligning them with modern safety standards poses unique challenges, often necessitating innovative retrofitting techniques. In this context, the present study offers a comprehensive investigation focused on the dynamic response and numerical analysis of an industrial historical chimney subjected to a specific retrofitting method.

The primary objective of this research is to assess the effectiveness of the employed retrofitting technique, which involves strategically placing metal rings to enhance the chimney's resistance against seismic forces.
Historical structures, such as the chimney under examination, frequently lack comprehensive original design information. Consequently, the research adopts a methodology that combines dynamic experimental testing, advanced numerical modeling, and seismic analysis to provide valuable insights into the behavior of the structure and the impact of the retrofitting approach.

Given the absence of fundamental structural information, all parameters utilized in the study are derived from practical experiments, ensuring an appropriate and accurate assessment. The experimental phase involves ambient vibration testing conducted in two stages, offering a precise understanding of the chimney's response to seismic excitation. Furthermore, the empirical findings validate the numerical modelling, enabling the simulation of structural behaviour under various conditions, both before and after retrofitting implementation.

The subsequent sections of this paper deals with specific methodologies employed, presenting the dynamic structural study, experimental procedures, and numerical analysis in detail. The obtained results are critically analyzed and discussed to reveal the extent of the retrofitting technique's influence on structural response. Through

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this comprehensive exploration, the study aims to contribute to a broader understanding of retrofitting strategies for historical and complex structures, providing valuable insights into their enhanced seismic performance.

2. Case study: Description of a Historical Chimney

The focus of this research is a chimney situated in the city of Tabriz, erected during the first Pahlavi period. This chimney is an integral component of the former Khosravi Leather Factory complex, which has been meticulously renovated and repurposed as part of the Tabriz Islamic Art University. Its construction is attributed to the year 1931 AD. However, no architectural blueprints or construction particulars are available. Consequently, all requisite information vital for this study—encompassing structural geometry and material properties—was acquired on-site and through diverse tests.(Nami, 2022, 3)

Due to the scarcity of substantial data and architectural blueprints, the comprehensive geometry of the industrial chimney was ascertained using laser scanning technology. Post the quantification of the structure's geometry, the architectural dimensions of the industrial chimney were determined. It takes the form of an incomplete hollow cone, standing at a height of 25.85 meters, with an octagonal base reaching to a height of 6.01 meters. At the base level, the outer diameter spans 4.7 meters, tapering to 1.9 meters at the summit. The wall thickness exhibits uniform variation, transitioning from 1 meter at the base to 0.40 meters at the uppermost point. (Nami, 2022, 3)

In recent years, this structure has undergone a retrofitting process involving the installation of 11 metal rings at approximately one-meter intervals encircling the chimney. Fig. 1-a presents a photographic portrayal of the chimney, while Fig. 1-b depicts documentation and intricacies of the structure subsequent to the measurement procedure.

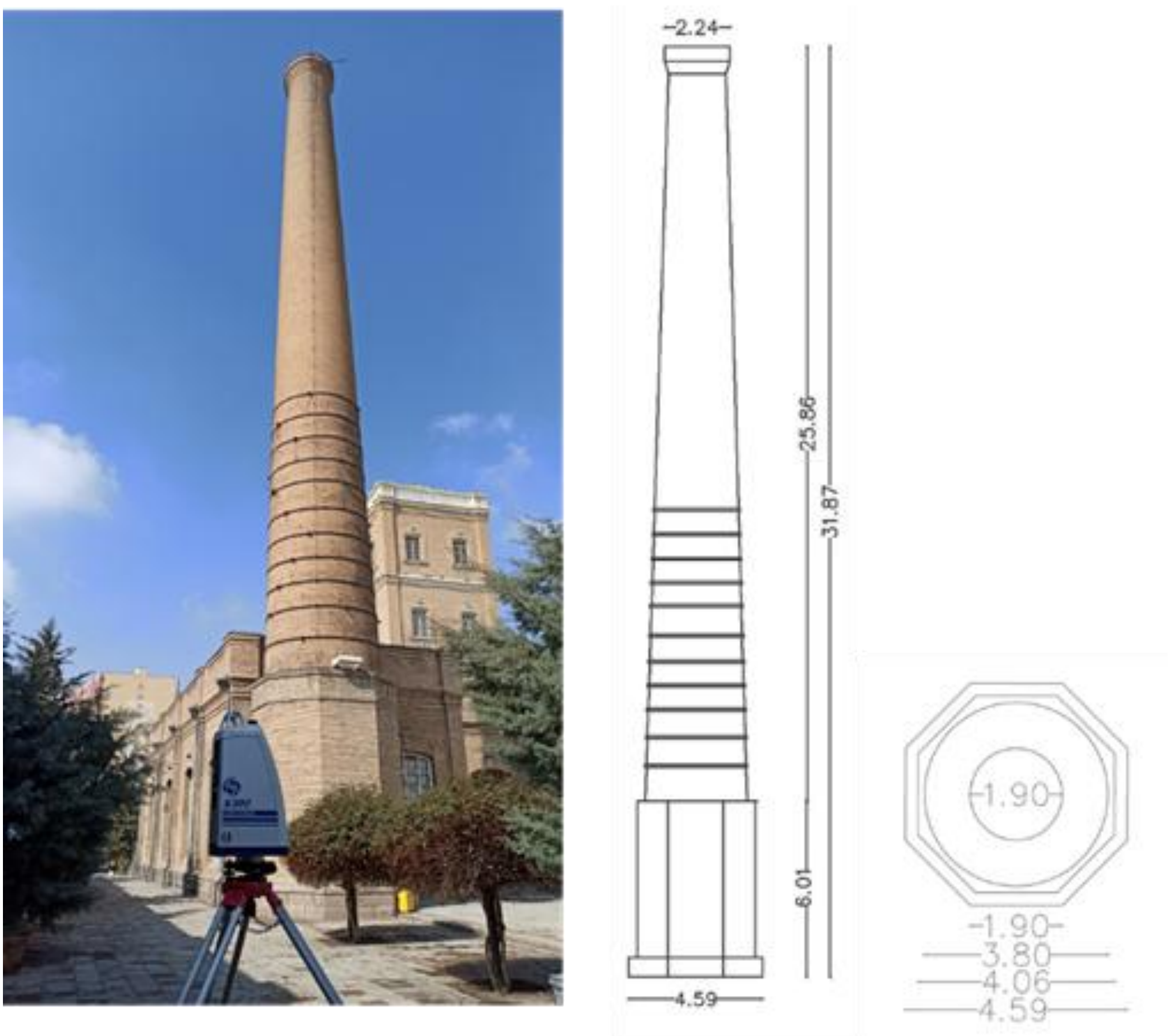

Fig.1. a:photo of chimney b: Geometric Specifications of masonry Chimney

2. Modal Testing

The identification of dynamic characteristics in structures holds paramount importance across diverse industrial domains, including automotive, aerospace, robotics, and civil engineering, among others.

Extensive research has been dedicated to both numerical and experimental techniques for identification of dynamic behavior of structures. Modal analysis, a laboratory-based method, stands as a suitable approach for characterizing dynamic parameters within structures and constructing a mathematical or modal model (Ghalishooyan, 2015). In civil structures, experimental modal parameter identification involves the extraction of modal parameters—comprising frequencies, damping ratios, and mode shapes—from dynamic measurements. These parameters serve multitude of purposes, including refining finite element models, detecting and pinpointing potential structural damages, conducting prolonged structural health assessments, and evaluating structural integrity subsequent to intense loading scenarios like earthquakes.

Nevertheless, numerous real-world structures pose challenges to the application of experimental modal analysis for acquiring modal parameters. Consider large-scale structures, where effectively stimulating the structure and measuring applied forces to the structure may be unfeasible. Many structures experience excitation due to forces stemming from their operational behavior, rendering the measurement of these forces impractical. Consequently, focus has shifted toward methods that obviate the necessity for direct excitation and force measurement in modal parameter identification. These methods are known as Operational Modal Analysis (OMA) or Ambient Modal Analysis, relying solely on recording structural responses to naturally occurring forces during routine operating conditions (Salehi, 2018, 55).

2.1. Experimental Procedure:

Ambient vibration tests were conducted by to determine modal parameters under two distinct conditions: prior to retrofitting and post-retrofitting (comprising natural frequencies and mode shapes).

The main objective of these tests was to update the numerical model of the chimney. The operational modal test was executed in a two phases. The initial phase encompassed subjecting the structure to testing under its existing state, including the presence of metal rings intended for retrofitting. In the subsequent stage, the metal rings, previously affixed to the structure for retrofitting purposes, were systematically removed to nullify their impact on the structure's behavior. In both stages, operational modal testing was conducted utilizing 12 cable-mounted accelerometers strategically positioned at 2.5-meter intervals. (Nami, 2022, 5)

The operational modal test is done as follows:

1. Placement of accelerometers at 2.5-meter intervals along the chimney's height.
2. Activation and interconnection of accelerometers with the data logger.
3. Capture and recording of data transmitted by the accelerometers through the data logger.
4. Formulation and extraction of relerant information and data for subsequent analysis.

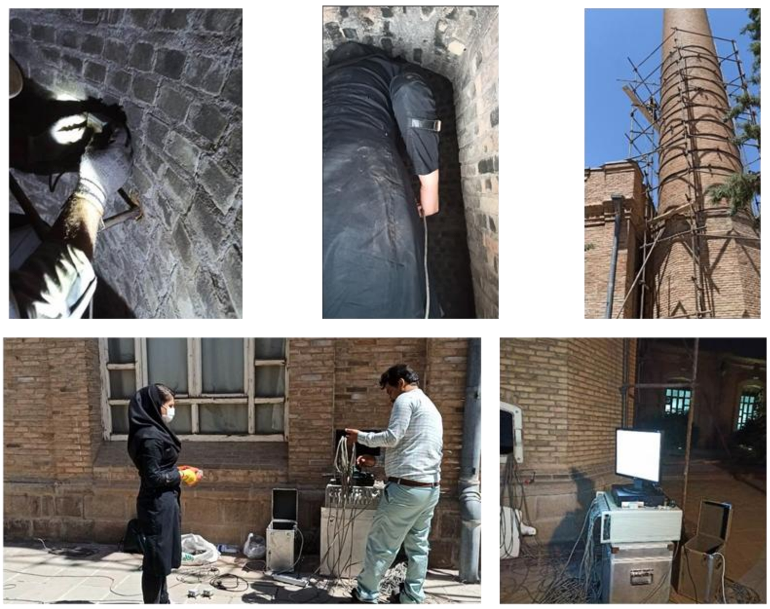

Fig.2. Stages of Operational Modal Testing

3.Numerical Modeling:

Numerical modelling and analyses encompass a scaled simulation of the investigated structure. The correctness of results increases as the simulation accuracy and detail improve, yet this progress necessitates a balance between computational requirements and time investments. Thus, the choice of modelling approach must be guided by project prerequisites. This study employed a macro-level modelling approach to streamline the numerical model and enhance computational efficiency.

Utilizing the information gleaned from the structure, as elaborated upon in preceding sections, a meticulous numerical model was constructed to execute the required analyses with the utmost precision. The finite element model utilized in this study adhered to a macro-level modelling methodology, focusing on simplification to conserve time and computational resources. The geometry of the chimney model is illustrated in Fig.1. The abridged structural representation encompasses a conical section measuring 25.85 meters in height with an average thickness of 0.7 meters, accompanied by an octagonal base section extending to a height of 6.01 meters. All elements within this model were treated as regular curved shells. The entire model comprised 7,907 elements and 7,945 nodes. The structural supports and foundation were also simplified, with all degrees of freedom constrained.

The material properties in this study are presented in table 1.

The compressive strength and elastic modulus were extrapolated from biaxial flat-jack tests, while the tensile strength was considered as 0.1 times the compressive strength.

4. Pushover Analysis:

Nonlinear pushover analysis constitutes a static approach for assessing the seismic performance of structures. The fundamental premise lies in the assumption that the structure under scrutiny can be simplified into a single-degree-of-freedom system in accordance with its seismic response. Inertial forces resulting from ground motion are approximated onto the structure through a lateral load distribution. A pushover analysis is a procedure in which the magnitude of the lateral load excited in a structure is increased monotonically until failure. The lateral load is applied in a predefined load pattern. Central to the Nonlinear Pushover (NLPO) method is the construction of a capacity curve. This curve delineates the correlation between base shear and node displacement, functioning as a pivotal parameter (Nortman, 2019, p. 32). Such a relationship characterizes structural capacity concerning peak force, deformation, and the capacity for deformation alteration.

In this study, a pushover analysis was conducted on the modelled structure to explore its seismic behaviour. The outcomes of the principal structure analysis, sans rings, were juxtaposed with the retrofitted state, incorporating metal rings. Fig. 3 depicts the capacity curve obtained from the pushover analysis of the structure before strengthening.

Table 1. Optimized values of the materials used in chimney model

Material	Elastic Modulus MPa	Specific mass Kg/m3	Poisson's coefficient	f_c MPa	f_t MPa
Masonry material	2340	1900	0.25	1.001	0.1001

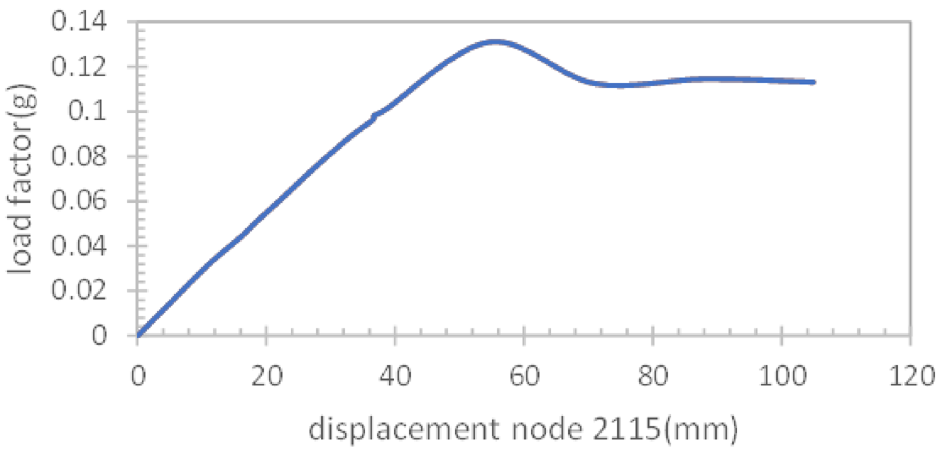

Fig.3. Pushover analysis

5. Structure After Retrofitting

Retrofitting a structure entails deploying techniques and strategies to bolster its performance against imposed loads. Within this study, the focus centers primarily on seismic forces, recognizing their significance, particularly in Tabriz city.

Fundamentally, all retrofitting strategies adhere to one of two principles: either mitigating seismic demand through these techniques or enhancing structural capacity against external forces. Consequently, a range of retrofitting options exists, with the optimal choice contingent upon factors like structural conditions, economic considerations, resource accessibility, requisite expertise, and more.

Within this project's framework and considering prevailing conditions, the application of metal rings emerged as the retrofitting technique for the analyzed structure. This research is centered on assessing the precise influence of this retrofitting approach. Accordingly, diverse implementations of this approach were executed on the modeled structure, each followed by pushover analysis using mass-proportional loading. Comparing the resultant capacity curves facilitates the assessment of structural resistance alterations post-retrofitting. These rings were linearly modeled as Beam Class III elements (Fig. 4).

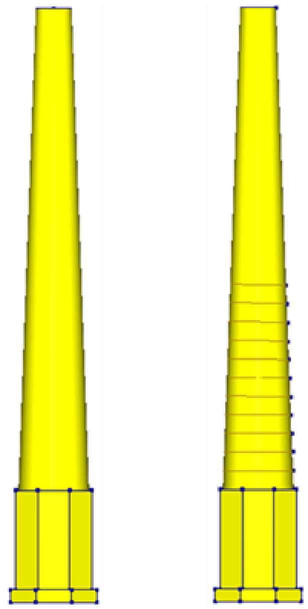

Fig.4. Model of chimney a: without rings b:after strengthening with rings

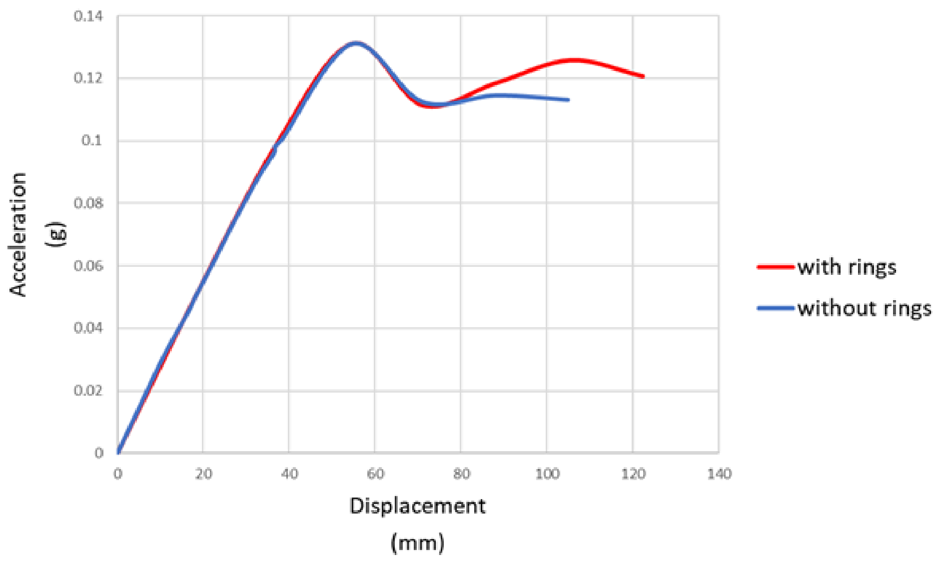

Fig.5. Comparison of pushover analysis before and after strengthening with rings

After several iterations of analyses and placing rings at different heights, the most optimal configuration was achieved at one-third of the chimney's height. (Fig. 6).

Based on the curves depicted in Fig.7, under the most optimal utilization of metal rings in this structure, the structural resistance observed a rise of approximately 9.16% compared to its pre-retrofitting state. However, this percentage increase does not meet the criteria for satisfactory structural retrofitting.

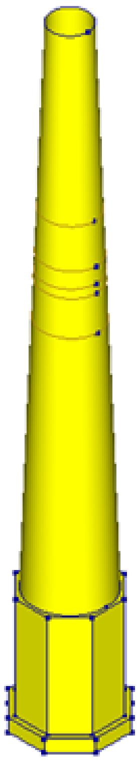

Fig.6. Model of chimney after strengthening with rings at one-third of the chimney's height from the top

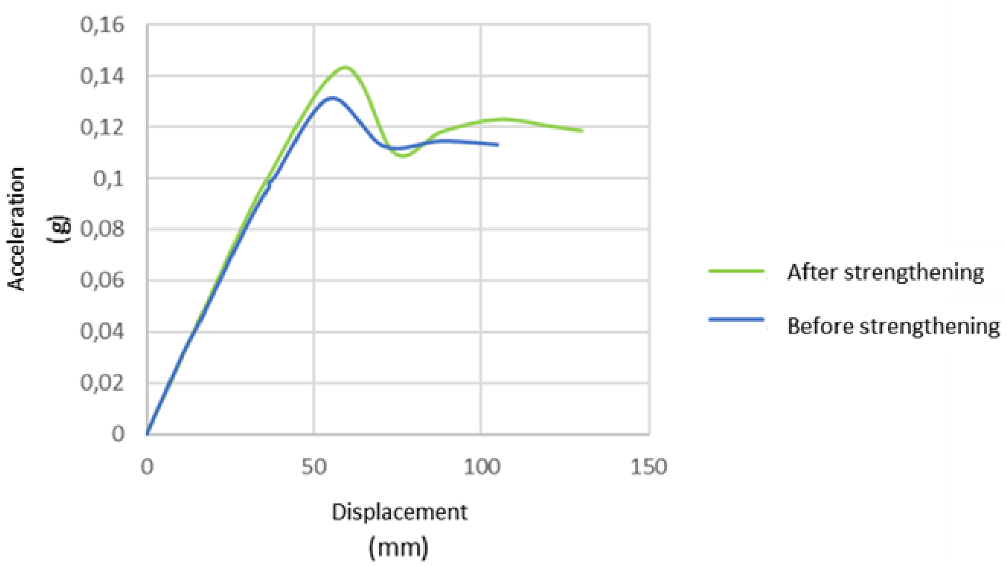

Fig.7. Comparison of pushover analysis before and after strengthening with rings at one-third of the chimney's height from the top

6. Conclusion

In light of the findings, it is evident that the chosen retrofitting method involving the placement of metal rings had a limited impact on overall structural integrity enhancement. Comprehensive numerical modeling and seismic analysis revealed that the retrofitting approach resulted in only an 11.5% increase in structural resistance when the metal rings were optimally positioned one-third from the top of the chimney. Placing the rings under current conditions had no effect on strengthening the structure. This modest improvement falls short of meeting the necessary strengthening requirements for the subject structure.

In conclusion, while the investigation provided valuable insights into the behavior of the industrial historical chimney under the retrofitting technique, the results highlight the limitations of this approach in significantly enhancing structural robustness. The study underscores the importance of considering alternative or supplementary retrofitting strategies to achieve the desired level of structural improvement, particularly in the context of historical and complex structures, where achieving substantial gains in resistance may require more advanced interventions.

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Vulnerability assessment of Holy Mary Historical Church in East Azerbaijan, Iran according to Italian Guidelines

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Abstract. Iran, renowned for its rich architectural heritage, is located in an earthquake-prone region, which necessitates the preservation of historical monuments. The East Azerbaijan province, in the northwest region of the country, houses numerous significant heritage sites, notably several historical churches. However, research indicates that only 13 out of 49 churches within the province remain standing, with many having been either destroyed or left in disrepair. A particularly noteworthy example is the Church of Holy Mary, an important architectural heritage site that features distinctive elements of Armenian ecclesiastical architecture. This church was constructed in AD 1518 in the town of Jolfa, along the banks of the Aras River. This study's primary objective was to conduct a comprehensive assessment of the seismic safety of the Holy Mary Church utilizing qualitative methods. This was accomplished through field surveys and extensive library research to ensure a thorough understanding of the church's historical context as well as its architectural and structural features. Following this, the qualitative approach was adopted based on Italian guidelines for evaluating and mitigating seismic risks to cultural heritage to assess the church's seismic vulnerability. The findings revealed a seismic safety index of less than 1, which indicates that the church does not have sufficient safety measures to withstand potential seismic events. This study underscores the critical need to integrate qualitative assessments for the preliminary evaluation of historical buildings' seismic safety, as it is an effective method for quickly estimating a building's safety status before any interventions.

Keywords: architectural heritage; seismic assessment; historical church; Italian guideline; East Azerbaijan Iran

1. Introduction

Religious heritage is culturally and spiritually significant. It embodies a community's history, art, and traditions, while serving as a spiritual center and home for believers. Christian buildings in Iran hold a significant role in representing the country's multiculturalism. These stunning structures, built with grandeur and unique architectural techniques, serve as a testament to the Christian community's rich history in this region, despite their dwindling numbers due to migration. In the meantime, Armenian churches in Iran, especially in East Azerbaijan province, are clear examples of various cultural, social, and religious interactions that indicate the cultural diversity of this region. Historical Armenian churches are a symbol of Armenian culture and architecture from the distant past to the present, as well as a sign of coexistence and ethnic interactions in Iran's history. These buildings showcase the creativity and vitality throughout this multi-millennial geographical space where civilizations have intersected. However, research data reveals that only 13 of the 49 churches in East Azerbaijan province remain standing, with many having been destroyed or fallen into disrepair. (Malekmian, 2001) Therefore, preservation of these historical monuments is crucial, especially in regions prone to earthquakes. Located on the Alpine-Himalayan earthquake belt, Iran is one of the seismically active regions of the world (Abdollahzadeh et al., 2014), and the East Azerbaijan region in North-western Iran is one of the most seismic regions of the country, having experienced many seismic events during its long history (Standard No. 2800, 2014)

As a result, there is an urgent need for structural and seismic evaluation of these buildings to assess their vulnerability and prevent potential destruction. Evaluating the seismic performance of historical monuments is essential for protecting architectural heritage and creating effective preservation strategies. Understanding the structural behavior of these buildings is a crucial first step in this process.In this regard, the Italian guideline "Guidelines for evaluation and mitigation of seismic risk to cultural heritage" (DPCM, 2005) is proposed as a reliable source of guidance that can be employed for the vulnerability assessment of heritage buildings under seismic loads.(Torelli et al., 2020).

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These guidelines can be used as a scientific and practical basis for the protection of cultural heritage, especially the Armenian churches of East Azerbaijan. This guideline introduces qualitative methods for assessing the vulnerability of various historical monuments. These include villas and buildings with bearing walls and horizontal diaphragms, religious structures and large halls without intermediate diaphragms, as well as towers and bell towers, other slender structures. Additionally, it covers masonry bridges, triumphal arches, and other arch-based structures.

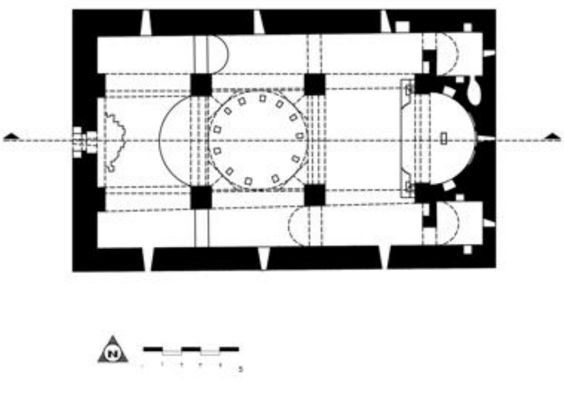
In 2023, a seismic vulnerability assessment of Ali Monsieur House in Tabriz, Iran, was conducted using Italian guidelines, applying a qualitative analysis method suited to buildings with bearing walls and horizontal diaphragms (Gholami & Akhoundi, 2023). This article aims to focus on the vulnerability assessment of the Holy Mary Church in East Azerbaijan, Iran, employing the qualitative method designed for religious structures with large halls. With a rich history dating back to AD 1518, the Holy Mary Church, belonging to the Armenian Gregorian sect, stands as one of the most significant and oldest Armenian churches in East Azerbaijan. This church presents a unique opportunity for assessing seismic vulnerability and developing conservation solutions. In addition to exploring the architectural features and historical context of the Holy Mary Church, this article will provide a qualitative assessment of its current condition based on the established Italian guidelines.

2. Case study: Holy Mary church

The Church of the Holy Mary, demonstrated in Fig. 1, was built in AD 1518 on the scenic slopes of the Sham Valley, overlooking the Aras River. (Karang, 1351). This historical site reflects the architectural style of its era and serves as an important cultural landmark for the local community.

The Church of the Holy Mary of Jolfa is designed as a three-nave basilica. The interior showcases vaulted ceilings, and the exterior features a gable roof. A magnificent high dome is prominent at the center of the Holy Mary church, visible from both the inside and outside of the church. The walls and vaults are constructed from stone, while the dome is made of brick.

Fig. 1. Eastern facade of Holy Mary church (Left: Archives of the Cultural Heritage Organization, East Azerbaijan Province) (Right: Author)



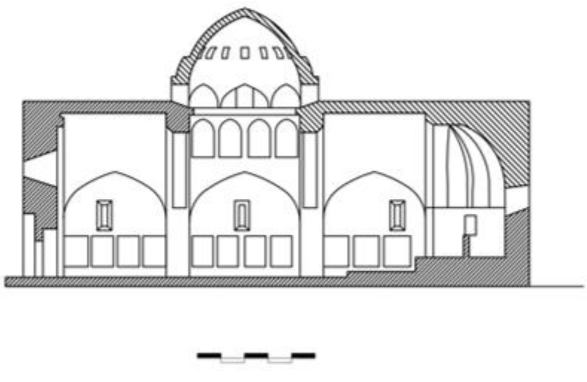


Fig. 2. Left: Plan (Hoviyan, 2003), Right: Section of the Holy Mary church (Hoviyan, 2003),

The church measures twenty-two meters and thirty centimeters in length and thirteen meters and fifty centimeters in width. The dimensions of the apse are four meters and eighty centimeters by three meters and twenty centimeters. The apse stands eighty centimeters higher than the church ground level, and there are two rows of stairs on both the northern and southern sides of the apse, providing access to it. Inside the church, four columns are arranged in two rows. Each column has a square cross-section with each side measuring one meter. The distance between the columns is four meters and eighty centimeters, and they are connected by a truss arch (Hoviyan, 2003). Plan and cross-section of the church are presented in Fig.2.

The spaces between the arches are filled with rubble stone and mud mortar. The dome, featuring twelve skylights, is supported by brick pendentives constructed in the spaces created by the arches.(Fig. 3) The layout of the streets surrounding the church, along with the remnants of villagers' houses (Fig. 4), indicates that many homes once existed in proximity to the church. (Hoviyan, 2003)

Fig. 3. Dome, pendantives and skylights (Left: Archives of the Cultural Heritage Organization, East Azerbaijan Province, Right: Author)

Fig. 4. Holy Mary church and the ruins of the ancient village of Darreh Sham (Archives of the Cultural Heritage Organization, East Azerbaijan Province)

3. Materials and methods

This study utilized qualitative methods to investigate the seismic behavior of the Church of the Holy Mary. To this end, a comprehensive examination of historical documents, maps, and old photographs was conducted to gain insight into the church's history, structure, and previous damage. By understanding the architectural style and historical significance of the church, a more thorough assessment of its vulnerabilities can be achieved. Additionally, a field visit was conducted to assess the condition of the building, focusing on structural damage, cracks, signs of deterioration, and the surrounding environmental conditions. Photographs and videos were captured from various angles of the church for accurate documentation, allowing for a detailed visual record of its current state. Moreover, a qualitative evaluation of the building was performed using the Italian conservation guidelines based on the data gathered. This comprehensive approach not only enhances the understanding of the church's seismic vulnerability but also aids in planning future restoration efforts.

3.1. Qualitative analysis

The qualitative assessment in this study follows the method outlined in the "Guidelines for Evaluation and Mitigation of Seismic Risk to Cultural Heritage". These guidelines, established since 2005, are designed to align with Italy's technical standards for reducing seismic risk and protecting historical buildings. The primary objectives of these guidelines are to provide a method for identifying buildings, assessing their seismic safety, and designing retrofitting interventions all while considering the historical characteristics of each structure. The guidelines provide specific assessment methods designed for the different geometries of buildings. In particular, they introduce a qualitative assessment approach for structures featuring large halls without intermediate diaphragms. For example, the seismic behavior of buildings like churches is analyzed by separating it into macro-elements, which can include façades, halls, apses, bell towers, vaults, and triumphal arches. Each of these components behaves independently in relation to the entire structure of the church.

This methodology thoroughly examines 28 damage mechanisms all of which are outlined in Table 1. Each mechanism is associated with various macro-elements typically found in religious buildings, helping to clarify the specific vulnerabilities or measures each structure may face. By utilizing the correct form, it is possible to establish a vulnerability index (1).

$$i_v = \frac{1}{6}\frac{\sum_{K=1}^{28}\rho_k(V_{ki}-V_{kp})}{\sum_{K=1}^{28}\rho_k} + \frac{1}{2} \quad (1)$$

The next step after calculation of the vulnerability index is to calculate the accelerations corresponding to limit state of damage and ultimate limit state based on 5.16 and 5.17 equations on DPCM (2005) and thereby the seismic safety index of the church (2) (DPCM, 2005).

$$I_S = \frac{a_{SLU}}{\gamma_i S\, a_g} \quad (2)$$

The importance factor of the building, referred to as γ_i is determined based on DPCM (2005) - Table 2.1. The coefficient related to the soil and foundation layers is represented by S and is determined according to NTC18 (Code, I. B., 2018). The design basis acceleration, ag, is established in accordance with the Iranian Seismic Code (Standard 2800). In this context, if the value obtained for I_S is greater than one, the building is resistant to seismic events, and if this value is less than one, the building does not have the expected safety.

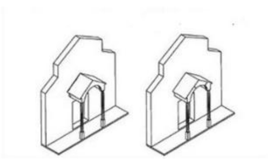
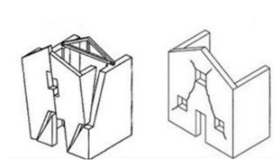
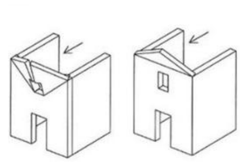
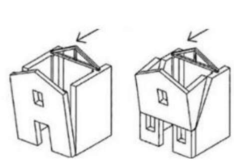
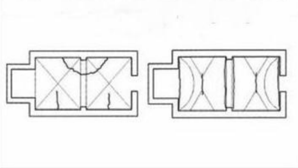
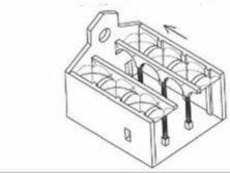
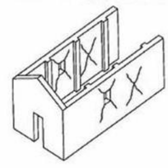
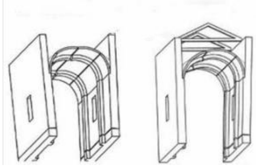
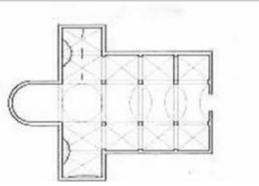
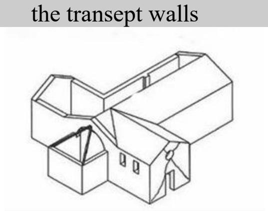
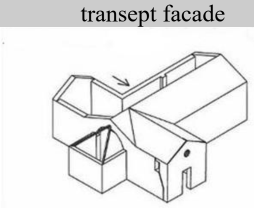
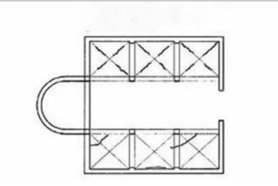
3.1.1. Reference limits for cultural heritage

For historic architectural structures, ensuring safety and protection against seismic risks involves two key objectives. First, there is a focus on safeguarding occupants from potential dangers during rare, high-intensity earthquakes, known as the Ultimate Limit State (SLU). Second, it aims to reduce economic and functional damages that may occur during more common, low-intensity earthquakes, referred to as the Limit State of Damage (SLD). The specified limit states are as follows:

•The Ultimate Limit State (SLU) pertains to a building's condition during earthquakes with a 10% probability of occurrence in 50 years.

•The Limit State of Damage (SLD) evaluates the condition during earthquakes with a 50% probability over the same period (DPCM, 2005).

Table 1. 28 damage mechanisms in the churches (DPCM, 2005)

Mechanisms			
4- Nartex	3- Shear mechanisms in the facade	2- Damage at the top of facade	1- Overturning of the facade
			
8- Vaults of the nave	7- Longitudinal Response of the colonnade	6- Shear mechanisms in the side walls	5- Transversal vibration of the nave
			
12- Vaults of the transept	11- Shear mechanisms in the transept walls	10- Overturning of the transept facade	9- Vaults of the aisles
			
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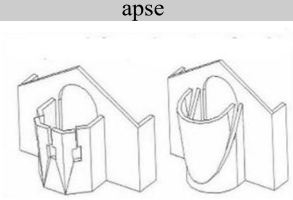
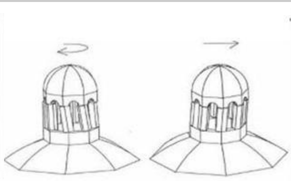
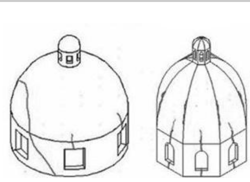
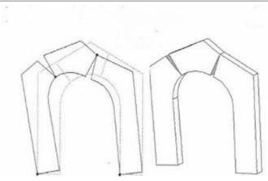
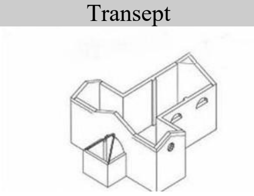
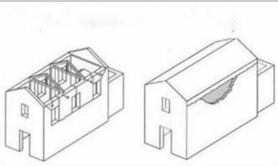
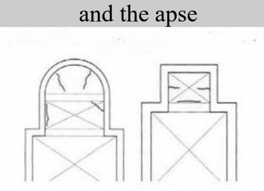
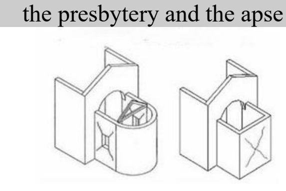
			
20- Roof mechanisms: Transept	19- Roof mechanisms: side walls of nave and aisles	18- Vaults in the presbytery and the apse	17- Shear mechanisms in the presbytery and the apse
			
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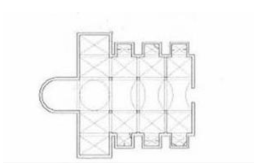
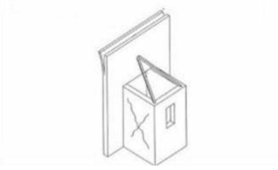
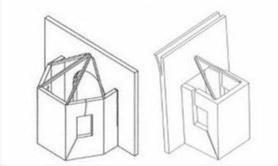
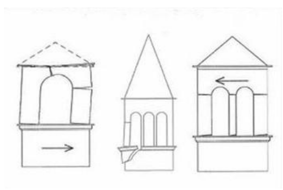
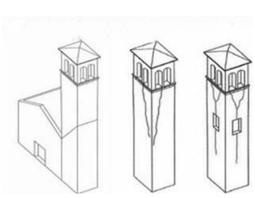
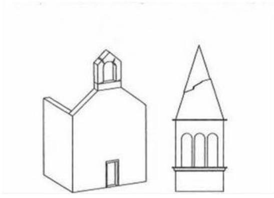
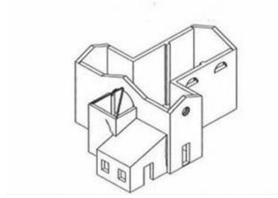
			
28- Belfry	27- Bell tower	26- Projections(gable belfry, spires, pinnacles, statues)	25- Interactions with adjacent buildings
			

Table 2. Scoring table for qualitative assessment of the Holy Mary Church

Mechanisms (Holy Mary Church in Jolfa)	**Aseismic measures**	**Vulnerability Indicators**	***Weight attributed to the mechanism*** (ρ_k)	V_{kp}*	V_{ki}**
Overturning of the facade	0	1	1	0	2
Damage at the top of facade	0	0	1	0	0
Shear mechanisms in the facade	0	0	1	0	0
Nartex					
Transversal vibration of the nave	0	1	1	0	2
Shear mechanisms in the side walls	0	0	1	0	0
Longitudinal Response of the colonnade	0	1	1	0	2
Vaults of the nave	0	0	1	0	0
Vaults of the aisles	0	0	1	0	0
Overturning of the transept facade					
Shear mechanisms in the transept walls					
Vaults of the transept					
Triumphal arches	1	1	1	1	2
Dome, Drum and Tiburio	0	1	1	0	1
Lantern					
Overturning of the apse	0	1	1	0	1
Shear mechanisms in the presbytery and the apse	0	1	1	0	1
Vaults in the presbytery and the apse	0	0	0.5	0	0
Roof mechanisms: side walls of nave and aisles	0	2	1	0	2
Roof mechanisms: Transept					
Roof mechanisms: Apse and Presbytery					
Overturning of the chapels					
Shear mechanisms in the chapel walls					
Vaults of the chapels					
Interactions with adjacent buildings					
Projections (gable belfry, spires, pinnacles, statues)					
Bell tower					
Belfry					

*Grade of effectiveness in vulnerability indicators
**Grade of effectiveness in aseismic measures

Through a comprehensive field visit and inspection focused on macro-elements and the associated damage mechanisms, as well as an assessment of vulnerability indicators and the aseismic measures relevant to these mechanisms, a scoring table has been derived, which is presented in Table 2. Additionally, the detailed descriptive form of Table 4 is expanded in Table 3, where it incorporates aseismic measures alongside vulnerability indicators. This detailed analysis is particularly relevant for the active mechanisms observed in the Holy Mary Church.

Table 3. Asiesmic measures and Vulneability indicators in active mechanisms of Holy Mary church

Active Mechanisms	**Aseismic measures**	**Vulnerability Indicators**
Overturning of the facade	-	✓ Presence of thrusting elements (vaults)
Damage at the top of facade	-	-
Shear mechanisms in the facade	-	-
Transversal vibration of the nave	-	✓ Presence of vaults and arches
Shear mechanisms in the side walls	-	-
Longitudinal Response of the colonnade	-	✓ Presence of heavy vaults in the central nave
Vaults of the nave	-	-
Vaults of the aisles	-	-
Triumphal arches	✓ Adequate arch thickness	✓ Presence of Dome, Drum and Tiburio
Dome, Drum and Tiburio	-	✓ Presence of large openings in the drum
Overturning of the apse	-	✓ Presence of thrusting vaults
Shear mechanisms in the presbytery and the apse	-	✓ Heavy roof coverings
Vaults in the presbytery and the apse	-	-
Roof mechanisms: side walls of nave and aisles	-	✓ Presence of static thrusts in the roof ✓ Heavy roof coverings

4. Results and discussion

The qualitative assessment of the Holy Mary Church's structural integrity, based on calculations stemming from relations 1 and 2, as well as equations 5.16 and 5.17 outlined in the DPCM (2005), has yielded notable findings, which are presented in Table 6. The safety index of the Church was evaluated under two distinct conditions: the ultimate limit state (SLU) and the limit state of damage (SLD). The analysis reveals safety indices of 0.250 and 0.235, respectively, both of which are less than 1. This indicates a concerning vulnerability of the structure to seismic events with a 10% and 50% probability of occurrence within a 50-year period. Furthermore, as displayed in Table 6, the vulnerability index for the Church of St. Mary is quantified at 0.648. It is essential to note that this vulnerability index systematically excludes the seismic characteristics of the site and the local soil conditions; these elements are integrated within the safety index calculations. Consequently, the results highlight the multifaceted nature of structural vulnerability in relation to seismic risks.

Table 4. Results of the qualitative assessment

	Inspector analysis	Sensitivity analysis
Vulnerability index	0.648	0.583 $<i_v<$0.690
Acceleration corresponding to limit state of damage (a_{SLD})	0.033g	0.038g$>a_{SLD}>$ 0.031g
Acceleration corresponding to ultimate limit state (a_{SLU})	0.135g	0.154g$>a_{SLU}>$ 0.124g
Safety index (a_{SLD})	0.235	0.268$>I_s>$ 0.216
Safety index (a_{SLU})	0.250	0.285$>I_s>$ 0.229

The results of the sensitivity analysis indicate that the vulnerability index of the assessed structure ranges from 0.583 to 0.690. This finding highlights a concerning level of vulnerability when subjected to potential seismic activities. Furthermore, the analysis of the safety index reveals that, under the limit state of damage, the values fluctuate between 0.216 and 0.268, and for the ultimate limit state, the range extends from 0.229 to 0.285. These results suggest that the seismic safety index of the building, based on both the researcher's evaluations and the sensitivity analysis, is below the critical value of 1. This indicates that the structure may not be sufficiently strong to withstand seismic forces. By incorporating sensitivity analysis into the assessment process, we enhance the reliability of the findings and reduce the chances of personal bias affecting the evaluation. This approach leads to a more objective understanding of the building's safety status and highlights the need for further improvements to meet necessary safety standards against seismic risks.

5. Conclusions

The first step in preserving historical monuments is to assess their seismic performance, which is crucial for both their conservation and safety. These historic structures are often vulnerable during seismic events due to a combination of factors, including material degradation, structural settlement, excessive weight, and inadequate maintenance. Therefore, evaluating these buildings is extremely important. One of the primary methods for assessing seismic performance is the qualitative method. This study presents a qualitative evaluation of the historic Church of St. Mary, based on Italian conservation standards. St. Mary is recognized as one of the oldest Armenian churches in Iran, with a history dating back to 1518. Given its location in a seismically active region and its status as the sole remaining testament to a once-thriving historical village, the need for a seismic assessment of this building is significantly underscored. This article not only examines the architectural and historical features of St. Mary but also provides a qualitative evaluation of its condition using Italian guidelines.

The results of the safety index derived from the qualitative assessment conducted by the inspector revealed values of 0.250 for the ultimate limit state and 0.235 for the limit state of damage. Furthermore, the sensitivity analysis indicated that the safety index for the ultimate limit state ranged from 0.229 to 0.285, while the limit state of damage yielded a range between 0.216 and 0.268. These findings suggest that the seismic safety index of the building, as assessed through both the researcher's evaluation and the sensitivity analysis, is below 1, indicating that the structure does not adequately withstand seismic events. It is important to note that integrating sensitivity analysis into the qualitative evaluation the impact of subjective interpretations by the researcher has been minimized, resulting in enhancing the reliability of the assessment of the building's safety status.

All these results highlight the vulnerability of the Holy Mary Church structure to potential seismic events in the region. A review of the safety indices for the limit state of damage and the ultimate limit state suggests that this church is at risk from both rare, high-intensity earthquakes and more frequent, lower-intensity seismic events. The qualitative assessment method is an effective and widely recognized tool in the seismic evaluation of buildings, enabling a prompt estimation of safety prior to any interventions and facilitating the development of effective conservation strategies.

Recognizing the consequences of neglecting seismic safety in historic churches such as the Holy Mary is particularly important, especially in earthquake-prone regions like northwestern Iran, where many churches have been destroyed or fallen into disrepair. This study highlights the urgent need for increased awareness and specialized efforts concerning the preservation of Armenian churches in Iran. These structures represent more than just relics of the past; they are living embodiments of a rich cultural heritage and vital connections to the region's multicultural history, deserving preservation for future generations.

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In the context of protecting Ankara's modern architectural heritage: Anafartalar Street

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Abstract. Ankara, which was declared as the capital of the Republic, has hosted the designs of famous and valuable architects with its rapid development activities. These valuable examples are concentrated in the Ulus and Yenişehir axes that form the old city center. Anafartalar Street is an approximately 1.5 km long street that starts from Ulus Square, turns in front of the old municipality, and ends in Samanpazarı. All of the structures bordering the street were built during the republican period; some of them have been preserved until today in the form they were built in the early republican period. However, these structures, which experience problems such as development activities in the region, rent, infrastructure and superstructure problems, unqualified functional changes, and neglect, are losing their original characteristics and becoming obsolete. Within the scope of this paper, the original architectural examples that have survived to the present day on Anafartalar Street have been typologically analyzed and detailed according to their periods and architectural features. The problems of the street, along with buildings changes and deteriorations, have been identified and examined under headings. The original structures identified have been evaluated within the scope of protecting modern architectural heritage within the context of DOCOMOMO, UNESCO, and the European Council regulations and recommendations. The data obtained have shown that there are unique examples built by pioneer architects in different architectural periods in the study area, but despite the fact that the structures are registered, changes and transformations, especially those originating from unqualified commercial functions and infrastructure/superstructure problems have hindered protection.

Keywords: Early Republican Architecture; Modern Architectural Heritage; Conservation; DOCOMOMO, Restoration

1. The Importance and Formation of Anafartalar Street

Ankara was founded in a mountainous region around the Hatip Stream on fertile lands fed by numerous streams south of the Çubuk plain. The data shows that the first settlement in Ankara began in the Phrygian period. The Lydians and Persians then ruled the city in turn. The city, which was taken by Alexander the Great, was captured by the Galatians in the 3rd century BC. The Tectosags, the raiding tribe of the Galatians, chose Ankara as their capital. After being captured by the Roman Emperor Augustus, the city continued as a large garrison. The temple, large - small baths, and gladiator graves that have survived from this period to the present day are in a way that tells us of the importance of the city. The city, which came under Seljuk rule in 1073 after the Roman period, was especially developed with mosques, madrasahs, and defensive structures during the reign of Alaaddin Keykubat. The Alaaddin Mosque, Ahi Şerafeddin Mosque, Ahi Evran Mosque, Akkale, and Akköprü are among the structures that have survived from this period. The city, which was under Mongol rule for a period and then under Eretnaoğulları rule, joined the Ottoman principality in 1354 and remained under the Ottoman Empire's protection until the republic's declaration.

In the second half of the 19th century, the reflection of the centralized management approach in the provincial cities on the space is seen in Ankara as the equivalent of the administrative structures built in the northwestern perimeter of the traditional city, in the area near the Hacı Bayram Mosque (Avcı, 2017). The arrival of the railway to the city in the early 1890s turned the new center, connected to the station street, into a focal point. Municipal services in Ankara, dating back to the 1860s, are carried out in the building designed in 1883, located on the branch of today's Anafartalar Street, formerly called Balıkpazarı Street, near the new center (Kolay, 2018:238-239) (Fig. 1)

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Fig. 1. Old Ankara Municipality Building (İ.Ü. Nadir Eserler Kutuphanesi, 90431-36)

Just before the declaration of the Republic, Ankara was declared the capital on October 13, 1923. With the declaration of the capital, a rapid population increase occurred, and the state made significant investments in the development of Ankara, whose population increased after it became the capital. The first studies that were initiated within this scope were zoning plans. However, in order to solve the housing problem of the population, which was 20,000 in the 1920s and reached 75,000 in 1927, and to accelerate zoning studies, Ankara Municipality was established by the law dated February 16, 1924, instead of Ankara Municipality, which had insufficient powers from the Ottoman period (Duru, 2012: 3; Çapa, 2020: 78).

The 1924 Ankara Municipality Map, which included the first planning decisions of the Ankara Republic, was prepared by a military commission (Cengizkan, 2004:19). The commission, established under the chairmanship of the Minister of Public Works at the beginning of 1924, prepared a city plan consisting of 4 sheets and submitted it to the Municipality. In the article written in the Hakimiyet-i Milliye newspaper dated 15 Kanunsani (January) 1924, it is stated that the first sheet of this plan covers the area around the Grand National Assembly, the neighborhoods around Bent Creek, and the vicinity of the Municipality Office. In the 1924 plan, it is seen that an axis with a linear line called Balıkpazarı Street starting in front of the Old Municipality Building was defined (Fig. 2). Upon determining that this plan was inadequate to meet the needs of the new capital, the Municipality commissioned Carl Lörcher to prepare a new plan. In the Lörcher plan, Anafartalar Street is located as a linear street starting from the front of the Municipality and connecting to the traditional center via Çıkrıkçılar hill (Cenzgizkan, 1927: 59).

Fig. 2. Balıkpazarı Street and the Municipality Building on the 1924 Ankara Municipality Map (Salt Archive: APLMMV06). (https://archives.saltresearch.org/handle/123456789/102344) (Adapted by the authors)

The importance of Anafartalar Street, which is currently formed by the combination of Karaoğlan Street, Balıkpazarı Street, and Cocuk Sarayı Streets, was realized with the acceleration of construction works in the 1920s. The area between Işıklar Street, Konya Street, and Anafartalar Street, which was destroyed by the fire of 1916, is one of the areas that was primarily planned and built (Tunçer, 2014; 27). The four buildings built by the public on Anafartalar Street are of great importance in Turkish Architecture with their period's successful and exemplary projects. Gazi and Latife Schools (1924) Courthouse (1925-26), Child Protection Agency General Directorate Building (1927, Arif Hikmet Koyunoğlu) (Aslanoğlu, İ, 2001) constitute the earliest important examples built on the street (Fig. 3). The importance of the structures is also understood from the fact that the street was known as Cocuk Sarayı Street during this period (Tuncer,2014;27). In addition to public structures parallel to the apartment development in Yenişehir, shops, inns, and passages continued to be built on the street along with the first apartment buildings of Ankara. During this period, Anafartalar Street became a center where all civil servants living in the Ulus district and its surroundings shopped. In the bazaar, where all daily needs could be met, many commercial activities such as luxury products such as furs, hats, carpets, jewelers, tailors, hairdressers, barbers, and photographers were carried out. This street, which was very important for Ankara, attracted attention with its apartment buildings, clean and wide sidewalks, and shops with awnings (Bilgen, 1985; 20).

Fig. 3. The newly constructed patronage (Himaye-i Etfal) building in Ankara (Servet-i Fünun, 14 April 1927)

However, the fact that the growth of the capital was confined within the historical city center caused different searches to emerge quickly; Anafartalar Street relatively lost its importance in its early years. In this context, the suggestion that Ankara should grow in the south direction is included in the Lörcher plan (Cengizkan, 2004) and is also reflected in the writings of intellectuals of the period. From Hamdullah Suphi Bey's article titled "Şehremini Haydar Bey" in the Hakimiyet-i Milliye newspaper dated June 11, 1924: *"It is a waste twice to stir up and move old Ankara too much; the result will be weak and inadequate. Secondly, we will spend more on fixing the old than making the new. The city should gradually move towards the southern ridges."* With the planning decisions taken in the Lörcher plan and the subsequent Jansen plan, Yenişehir was determined as the city center, and sub-centers such as Çankaya and Maltepe Kurtuluş emerged. Starting from the 1930's, public institutions were also moved to the Bakanlıklar area on the axis of the new center. For this reason, there was a change in the socio-cultural user profile on Anafartalar Street, and the houses on the street were generally re-functioned within a commercial context. Over time, with the involvement of unqualified trade, it became a region preferred by the middle and low-income groups; for this reason, some qualified buildings were demolished, and some changed and deteriorated.

The study conducted within the scope of this report focuses on the current state of Anafartalar Street due to its importance. It aims to identify the problems and present suggestions as a result of the analyses made with various field studies and observations of the street between 2022-2025.

2. Documented problems on Anafartalar Street

It has been determined that 106 buildings on Anafartalar Street are in both directions. 30 of these structures are registered. 11 of the registered structures are public structures. Structures with different functions built on the street starting from the 1940s are lined up on both sides of the street.
The problems detected in the field examination were evaluated in two categories: area- and structure-based.

2.1. Area-Based Problems Detected

In the examination carried out in the area, it was determined that traffic is one of the most important elements that damage the texture and structures. Anafartalar Street is the main artery connecting Ulus Center to Kurtuluş and Cebeci. The street constitutes the main artery providing access to important public or private health, education, culture, and administrative structures. For this reason, it constitutes a primary transportation axis and is used intensively. Although the street is primarily used one-way, it forms the route of more than 100 buses. In addition, the beginning of Çıkrıkçılar Street is the departure point of minibusses on the street, which is also a route for many others. In addition to public vehicles, the street is also used by private cars, freight vehicles of various sizes, taxis, and motorcycles.

One of the most important problems caused by this situation is the discharges on the ground due to vibration, cracks, and similar structural deteriorations in cultural assets. Vibration on the ground can be easily felt, especially when materials brought to wholesale businesses are transported by heavy tonnage vehicles. Another problem caused by heavy vehicle traffic is the discoloration and crusting problems caused by the condensation of carbon monoxide gas from vehicle exhausts on the building surfaces. This gas also forms carbonic acid when it falls to the ground with precipitation, damaging the surfaces.

Another problem caused by heavy vehicle traffic is the cars parked on the road or wherever considered appropriate. Since these vehicles park in several rows, pedestrian safety problems occur, and elderly, children, and disabled users cannot safely exit the sidewalk. It has been determined that parking is also done on the sidewalk, at the pedestrian crossing, at the door and garage entrance, and at the shop front on the street; and due to this situation, pedestrian safety cannot be provided even on the sidewalk. Although it has been observed that methods such as constantly having more than one traffic police officer in the area, warning with various warning signs, installing obstacles to prevent access to the sidewalk, and removing vehicles with tow trucks have been applied, it has also been determined that they have not been successful.

Fig. 4. Unplanned parking lots (a,b) ;Traffic jam and heavy vehicles on street (c,d)

Another problem related to heavy traffic is the unplanned use of every vacant building plot or every garden accessible from the street as a parking lot. This use affects the continuity of traffic due to the entrance and exit from the street; it also causes damage to the structures due to parking in the spaces between the structures. It has also been observed that vehicle and pedestrian safety cannot be ensured due to unplanned parking lots.

One of the problems detected in the area is the decrease in security, especially at night. During the fieldwork, it was determined that the trade and storage functions supporting this function were very intense. It is seen that the trade function is largely concentrated on businesses doing wholesale; there are very few businesses doing retail sales. Apart from the trade function, there are public institutions and organizations and very few small-scale restaurants in the area and the immediate vicinity.

The research conducted by Çıtır (2023) reveals a significant change in original functions. Within the scope of the literature data obtained, it was determined that the original function of most 106 structures was commercial, followed by housing, public administrative buildings, mosques, and school buildings. However, the situation in 2022 shows that the commercial function increased from 61% to 84%; functions such as education and health decreased; and the shelter function disappeared (Çıtır, 2023:54; 54; Koç et al. 2022).

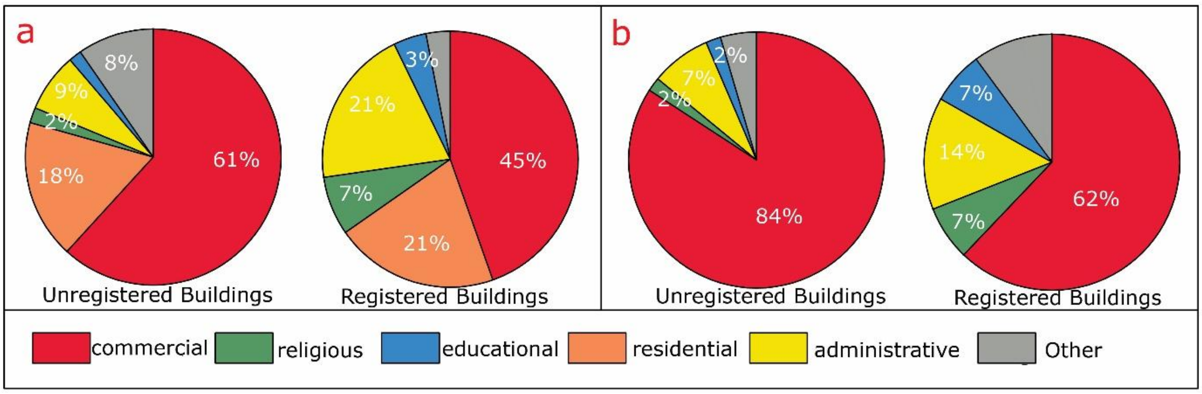

Fig. 5. Original function (a) and Current function (b) distribution graph of the buildings on Anafartalar Street (edited from Çıtır, 2023:54).

The increase in commercial use causes the area to be used intensively during the day but not at all in the evening, thus decreasing night security. The street becomes a place used by unwanted crime-prone groups at night; this causes qualified functions to move away from the area or not be located in this area.

It is seen that the original texture of the street has also been lost over time. After the demolition of the original structures, the unqualified and high-rise buildings built in their place prevent the visibility and perception of original and registered structures. It is seen that the height of the floors has increased over the years, and in this context, there has been a decrease in qualified structures. In the examination carried out in the area by Çıtır (2023), it was determined that there were 9 1-storey, 13 2-storey, 8 3-storey, 29 4-storey, 19 5-storey, 21 6-storey and three buildings higher than 6 (Çıtır, 2023:58).

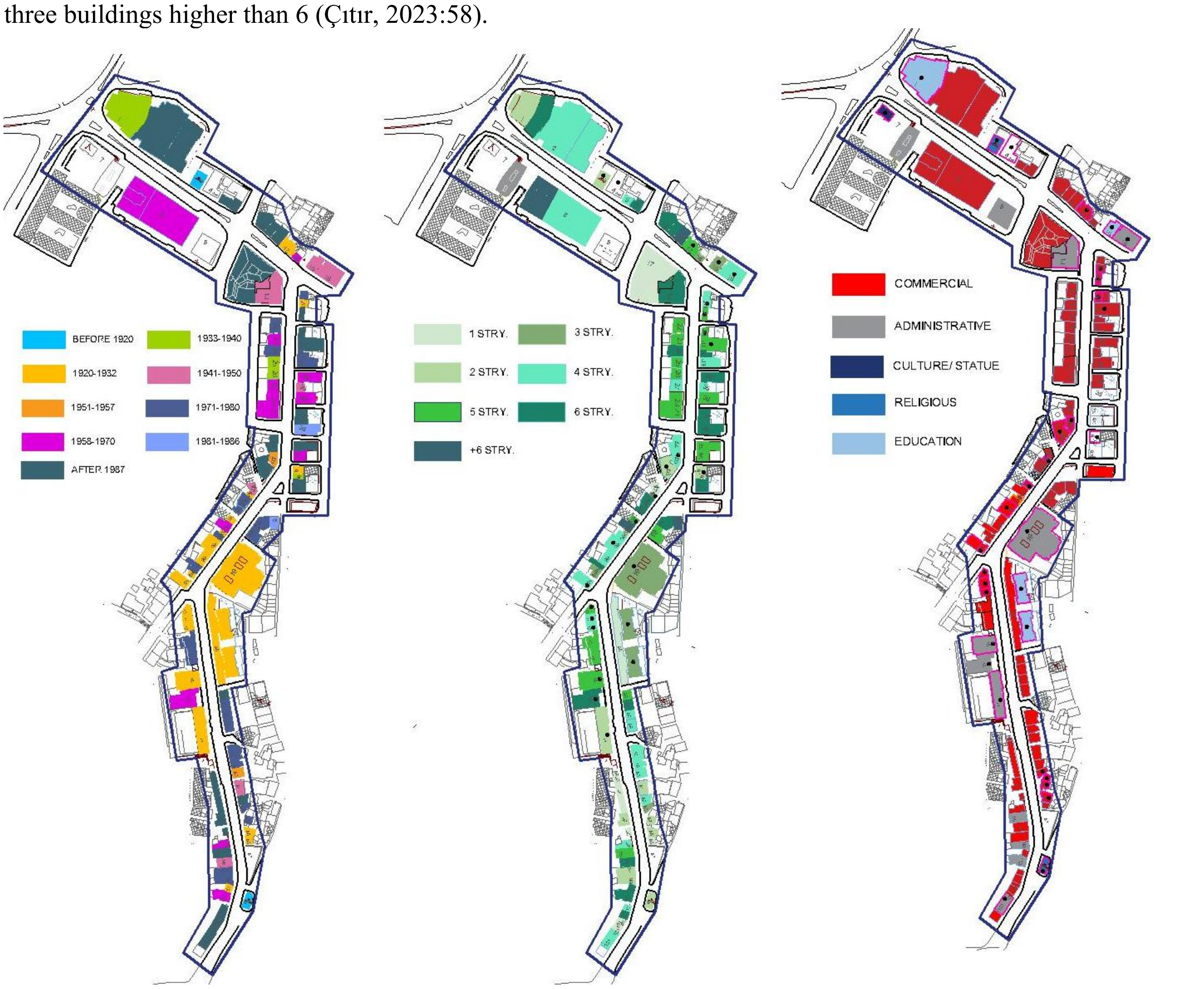

Fig. 6. Analysis of the construction date (A) (Çıtır, 2023:61). number of floors (B) (Çıtır, 2023:58) and Current function distribution graph (C) (Çıtır, 2023:54) of the buildings on Anafartalar Street

The study conducted by Çıtır (2023) determined that of the structures in the area, 25 structures, 19 of which are registered, were built between 1920-1930; 4 structures, 1 of which is registered, were built between 1930-1940; 6 structures, 3 of which are registered, were built between 1940-1950; 16 structures, 1 of which is registered, were built between 1950-1970; and 22 structures, 1 of which is registered, were built after 1970 (Çıtır; 2023:80). When the analysis of floor height and construction year is superimposed, it is seen that the floor height increases in the late-era structures.

2.2. Problems Identified Based on Structures
In the examination conducted in the field, it was determined that structure-based problems are generally related to function changes. Function changes are observed in most registered or unregistered qualified structures. This change is present in all residential structures; It is also seen in some commercial structures due to the change in the goods sold.

Fig.7. An apartment building example of inappropriate transformations (Kaya, 2023:65)

It is seen that the ground floors of the structures used as residences are especially transformed into commercial functions, and the upper floors are transformed into warehouses of these commercial enterprises. The biggest problem this transformation has caused is the conscious interventions such as transforming elements such as doors and stairs and breaking the walls to allow the space to take more materials since the structures were not built as warehouses. These interventions destroyed original elements; because of this, unqualified additions were made in their places. In the field examination, it can be seen that the upper floors continue to be used as warehouses. In the study conducted by Kaya in 2023; what was destroyed with the transformation of an apartment building adjacent to the street is revealed. This structure was built as a residence but transformed into a commercial function over time. It has been determined that the original elements of the structure were destroyed in order to easily stack the materials in the rooms within the scope of the transformation (Kaya, 2023:72). Another negative aspect of these transformations is the deterioration that occurs as a result of the lack of necessary cleaning and maintenance due to storage use. In addition to various accumulations, moisture, biological problems, and structural problems due to excessive load, such as plaster and paint peeling, breakage, etc., can also be seen during the transportation of the material.

Within the scope of functional transformations of buildings, there have been many examples of opening different entrances, especially to rent out commercial spaces on the lower floors by increasing them. In order to access these entrances from outside the building, unqualified staircases and similar additions have been made on different facades from different levels; the facade character and originality have been damaged. It is seen that some of these additions, which are generally preferred as metal, have also suffered severe deterioration and affected the facade. These interventions, which have been made on many different levels, also prevent the facade from being understood and read.

Unqualified additions to the side facades have also caused small commercial streets to form in front of these facades. In order to prevent the products exhibited in these streets to be shown to the customers from being affected by atmospheric conditions and to ensure that they can be walked around easily, these streets have been covered with unqualified upper covers. However, it is seen that these covers have adverse effects on the facades of the building, especially moisture, in addition to bad appearance. In addition, the structure's integrity cannot be understood due to these upper covers; the facades cannot be seen.

Fig. 8. Unqualified additions and changes on the rear sides of the buildings

Another element that negatively affects the integrity of the facades in buildings is large and colorful signs incompatible with the texture and structures. These signs are kept very colorful and large to be seen from a distance; they are designed even a few stories high depending on the functions on the upper floors. Since there are many side by side and one under the other, it is impossible to understand and perceive the facades. This pollution, which is very serious, especially in unregistered buildings, also causes structural damage due to the heavy loads that are tried to be attached to the facades of the building; traces of rusting iron remain and have an adverse effect as a moisture element on the facade.

Even if the function of the buildings does not change, unqualified interventions made to make them suitable for comfort conditions also create another problem. In this context, the most frequently encountered intervention is the air conditioning units hung on the facade. Since these units are fixed to any place on the facade to spend the least amount of material, they create strange and ugly images and look ugly. However, in examples where necessary maintenance is neglected, it is frequently seen that dirty water flows from the facade to the street when they are operated. In addition to being metal, the buttress irons that are fixed to the facade are also metal, so they rust and cause pollution. Because it is an important need in hot weather, many air conditioning units hung on the facade create a serious load in total, which causes an unexpected and uncalculated load to be added to the structure structurally.

Apart from air conditioning units, iron networks, railings for security purposes, and changed architectural elements are other types of deterioration. In this context, the changes that have come to our attention are elements that make it difficult to read the original elements. In addition, there are also many examples where cables are passed through the facades, and careless interventions are made, even if they do not damage the structure.

3. Conclusions

Anafartalar Street continued as the most important trade center and prestigious (distinguished) housing area of Ankara's capital from the Early Republican Period to the 1960s. The trade areas bordering it in the immediate vicinity, Samanpazarı, Çıkrıkçılar Yokuşu, Denizciler Street, and Ulus, brought liveliness, dynamism, and prestige to the economic and social life of Anafartalar Street. There are also social and cultural urban living areas and buildings in this area and its immediate vicinity where distinguished families live. Bakeries (Istanbul, Halk, Kadıköy, Akat, Akalın, Şark Bakeries), restaurants (Boğaziçi etc.), shops in different sectors (Jewellers, Eyüp Sabri Tuncer Store, Lale (Togo) Shoe, Sebat Pharmacy, İstanbul Pharmacy, Haim Kohen Shoe Shop - Atatürk's shoemaker-, Foto Ar, Foto Spor, Foto Rıdvan etc.), coffee houses (Kızılırmak, Taflan etc.), patisseries, Melek Cinema, Şengül Bath, Libraries (Gençlik, Tarık Edip Bookstore and Libraries), Child Protection Institution (Himaye-i Etfal) and the garden and swimming pool belonging to this institution and the surrounding residential areas were urban spaces used and shared by all city dwellers. Apart from public buildings, it is known that the city's first apartment buildings were also built on the Street. There were workplaces and shops on the ground floors of these apartment buildings (such as Talas, Dökmeci, and Hamamcızadeler Apartments).

With the restructuring of the capital with the Republic, the city and administrative center was shifted to Yenişehir, Kızılay, Bakanlık, and Ulus City Center, and therefore, Anafartalar Street began to lose its importance and value. In recent years, with the changing shopping style, the increase in large shopping malls preferred on an urban scale, and online shopping, the commercial life on Anafartalar Street lost its former liveliness and dynamism and collapsed.

Although commercial activities continued on Anafartalar Street during this change process, those who adapted to the changing commercial style (such as Boğaziçi Lokantası, Ayakkabı Dünyası) opened branches in the new city center and shopping malls and developed their commercial organizations and activities. Therefore, tradespeople and the local government did not care about this Street; no maintenance or repair was done on it for approximately 30-40 years. Thus, the Street began to become dilapidated. The fact that the existing houses do not have the comfort facilities of today's new centers is shifting from the Ulus region, and the elite families have left the area, which has caused both economic and social changes on the Street negatively. The fact that the tradesmen and users do not care about the old life habits and values, that they deny the historical, cultural and social values of the environment, or that they are not sensitive about these issues (such as advertising and sign pollution, the use of the Street as a parking lot, distrust of neighbors) are among the reasons for both the loss of prestige and the physical-spatial collapse of the Street. A rehabilitation project is currently being implemented on the Street. Within this study, it is seen that the problems that fall within the scope of simple repair in the structures have been resolved; unqualified applications, such as signs and billboards that cover the facades of the structures unnecessarily, have been removed or arranged. It has been observed that the signs are made in a single type with gray text on a black background, following a particular system so as not to cover the facade; unqualified coatings are removed, and a single type of black aluminum coating is applied; the architectural elements forming the facade are renewed in the same way, and the facades are painted, thus achieving a clean and healthy quality. However, the scope of restoring the Street to its former glory should be considered from different perspectives.

In this context,

- Preparation and dissemination of environments and information programs to raise awareness and sensitivity of commercial and business owners about the historical, cultural, and physical values of this Street,
- Tradesmen's participation in the Street's recovery efforts, their in-kind and cash support must be provided,
- Preparation and implementation of promotion programs for the city and even the entire country in order to protect the original characteristics of Anafartalar Street and its immediate surroundings and ensure sustainability,
- Programming of social and cultural activities (festivals, exhibitions, concerts, etc.) with the cooperation of tradesmen
- Following fair methods in recovery efforts, not giving privileges to individuals or institutions, and creating an environment of trust in this regard
- Ensuring the interest and support of local government(s), the Ministry of Culture, and all relevant civil society organizations (such as Ankara Chamber of Commerce, Ankara Tradesmen and Craftsmen Association, Ankara Jewelers' Chamber) in the subject,
- Urgent development of solutions regarding the transportation problem of the Street as much as (or primarily) improving the structures and/or physical-spatial structure and implementation,
- Determining the needs and expectations of the tradesmen in projects to be produced with the participation of the tradesmen in solutions aimed at increasing economic gain, which is the priority of the tradesmen,

- Considering the importance of the Street (starting from Hacıbayram and covering Kale and Hamamönü) within the urban scale "cultural tourism basin", developing and urgently implementing solution proposals regarding increasing the level of accessibility,
- Considering the location of the Street in Ulus Historical City Center, solving the parking problem, especially creating parking areas that will facilitate the access of vehicles belonging to local and foreign tourists to the Street.
- Immediately ensure security on the Street and its immediate surroundings, and take the necessary measures to illuminate the area at night.

It will ensure that the value of the Street is preserved and that the necessary measures are taken to pass it on to future generations both in terms of structure and structure. In this context, the fact that the region was included in the UNESCO temporary heritage list with the name "Ankara: The Planning and Building of a Republican Modern Capital City" on 11/04/2025 is also a very positive development. With this success, an important step has been taken in the positive transformation and development of the region.

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The impact of climate change on adobe structures in UNESCO World Heritage List

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Abstract. As the impacts of climate change increase and become more visible, understanding the vulnerability of cultural heritage values to climate change has become an integral part of conservation efforts. According to UNESCO, one in six cultural heritage sites is under threat due to climate change. To ensure the conservation of cultural heritage values, it is essential to investigate the effects of climate change on heritage sites and to develop solutions for their protection. Consequently, studies on the impact of climate change on cultural heritage have recently gained momentum.There is a growing interest in sustainable natural and traditional building materials to cope with the impacts of climate change. Due to its low energy requirements during production, recyclability, and lack of need for additional insulation, adobe has been used as an ecological and sustainable material throughout history. Structures built with adobe have been an essential part of local architecture in various cultures over the centuries. However, these structures can weaken due to climate-induced factors such as humidity, temperature fluctuations, and erosion.This study examines the deterioration of adobe materials used in structures located within UNESCO World Heritage cultural sites as a result of their exposure to climate change, as well as the conservation practices implemented or recommended to address such deterioration. By analyzing these cultural heritage assets, the study aims to create a literature resource on the conservation of adobe structures and materials.

Keywords: Climate change; Cultural heritage; Adobe; UNESCO World heritage list; Conservation and restoration

1. Introduction

Climate change is a global phenomenon that affects both tangible and intangible cultural heritage. Extreme weather events are causing damage to cultural values. These rising temperatures are accompanied by consecutive droughts and floods caused by intense rainfall. Changes in humidity levels, fluctuations in freeze-thaw cycles, and biological degradation pose further threats to historic buildings and sites (Pasikowska-Schnass, 2024). According to UNESCO, one in six cultural heritage sites is currently under threat due to climate change (Banjo, 2025). In order to preserve cultural heritage values, it is essential to understand the impacts of climate change on heritage sites and respond effectively (UNESCO Türkiye Milli Komisyonu, 2025). As the effects of climate change intensify and become more visible, understanding the vulnerability of cultural heritage to climate change is expected to become an integral part of conservation efforts (Perry & Falzon, 2025). For this reason, research on the impact of climate change on cultural heritage has gained significant momentum in recent years. Since the issue entered UNESCO's agenda, it has gained visibility through international discussions and continues to be examined in various publications.

Adobe, one of the most widely used building materials in the world, is produced by mixing earth, water, and certain additives. Due to the accessibility of its raw materials, adobe is typically produced on-site. Its characteristics—such as requiring little or no energy during production, being entirely recyclable, and not requiring additional insulation—have made adobe a preferred material in many structures throughout history (Zakar & Eyüpgiller, 2015).

2. UNESCO World Heritage List and Adobe Properties

The United Nations Educational, Scientific and Cultural Organization (UNESCO) aims to identify, protect, and preserve cultural and natural heritage around the world that is considered to be of outstanding value to humanity. This objective is articulated in the Convention Concerning the Protection of the World Cultural and Natural Heritage, adopted by UNESCO in 1972. What makes the World Heritage concept exceptional is its universal applicability. World Heritage sites, regardless of the territory on which they are located, belong to all peoples of the world (UNESCO, 2025a).

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Although there are numerous cultural heritage properties around the world, not all of them are included in the UNESCO World Heritage List. In order for a cultural heritage property to be inscribed on the World Heritage List, it must possess Outstanding Universal Value and meet at least one of the ten selection criteria established by UNESCO. These criteria are outlined in the Operational Guidelines for the Implementation of the World Heritage Convention. To reflect the evolving concept of World Heritage, the Committee periodically reviews and revises the selection criteria. Table 1 presents the content of the selection criteria defined by UNESCO (UNESCO, 2025b).

As shown in Table 1, Criteria I–II–III–IV–V and VI are related to the selection of cultural heritage properties, while Criteria VII–VIII–IX and X pertain to the selection of natural heritage properties. Within the scope of these criteria, there are currently 1,223 properties inscribed on the UNESCO World Heritage List. A search on the official UNESCO World Heritage website using the terms “adobe,” “mud-brick,” and “mud brick” yielded 28 heritage properties constructed with adobe materials. General information about these adobe heritage sites—such as their country, date of inscription, property category, and whether they are listed as in danger—is presented in Table 2.

Table 1. UNESCO World Heritage List Selection Criteria (UNESCO, 2025b)

UNESCO World Heritage List Selection Criteria		
Cultural Criteria	**I**	to represent a masterpiece of human creative genius
	II	to exhibit an important interchange of human values, over a span of time or within a cultural area of the world, on developments in architecture or technology, monumental arts, town-planning or landscape design;
	III	to bear a unique or at least exceptional testimony to a cultural tradition or to a civilization which is living or which has disappeared
	IV	to be an outstanding example of a type of building, architectural or technological ensemble or landscape which illustrates (a) significant stage(s) in human history;
	V	to be an outstanding example of a traditional human settlement, land-use, or sea-use which is representative of a culture (or cultures), or human interaction with the environment especially when it has become vulnerable under the impact of irreversible change;
	VI	to be directly or tangibly associated with events or living traditions, with ideas, or with beliefs, with artistic and literary works of outstanding universal significance. (The Committee considers that this criterion should preferably be used in conjunction with other criteria);
Natural Criteria	**VII**	to contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;
	VIII	to be outstanding examples representing major stages of earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features;
	IX	to be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;
	X	to contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Table 2. General Information on Adobe Properties in the UNESCO World Heritage List

UNESCO World Heritage List	**Country**	**Date of Inscription**	**Category of Property**	**In Danger**
Abu Mena	Egypt	1979	Cultural	Yes
Tchogha Zanbil	Iran	1979	Cultural	No
Archaeological Ruins at Moenjodaro	Pakistan	1980	Cultural	No
Old Walled City of Shibam	Yemen	1982	Cultural	Yes
Old Town of Ghadamès	Libya	1986	Cultural	Yes
Bahla Fort	Oman	1987	Cultural	No
Historic Centre of Lima	Peru	1988	Cultural	No
Old Towns of Djenné	Mali	1988	Cultural	Yes
Archaeological Sites of Bat, Al-Khutm and Al-Ayn	Oman	1988	Cultural	No
Taos Pueblo	USA	1992	Cultural	No
Coro and its Port	Venezuela	1993	Cultural	Yes

Table 2. continued

Archaeological Zone of Paquimé, Casas Grandes	Mexico	1998	Cultural	No
Tiwanakun Spiritual and Political Centre of the Tiwanaku Culture	Bolivia	2000	Cultural	No
Samarkand – Crossroad of Cultures	Uzbekistan	2001	Cultural	No
Ashur (Qal'at Sherqat)	Iraq	2003	Cultural	Yes
Cultural Landscape and Archaeological Remains of the Bamiyan Valley	Afghanistan	2003	Cultural	Yes
Bam and its Cultural Landscape	Iran	2004	Cultural	No
Pasargadae	Iran	2004	Cultural	No
Kunya-Urgench	Turkmenistan	2005	Cultural	No
At-Turaif District in ad-Dir'iyah	Saudi Arabia	2010	Cultural	No
Cultural Sites of Al Ain Hafit, Hili, Bidaa Bint Saud and Oases Areas)	United Arab Emirates	2011	Cultural	No
Historic Centre of Agadez	Niger	2011	Cultural	No
Shahr-i Sokhta	Iran	2014	Cultural	No
Aqueduct of Padre Tembleque Hydraulic System	Mexico	2015	Cultural	No
Arslantepe Mound	Türkiye	2021	Cultural	No
Sudanese style mosques in northern Côte d'Ivoire	Côte d'Ivoire	2021	Cultural	No
Dholavira: a Harappan City	India	2021	Cultural	No
Royal Court of Tiébélé	Burkina Faso	2024	Cultural	No

As seen in Table 2, the UNESCO World Heritage List includes properties from various countries around the world. The chronological range of inscriptions—beginning with Abu Mena and Tchogha Zanbil in 1979 and extending to the Royal Court of Tiébélé in 2024—demonstrates the continued acknowledgment of adobe architecture as a valuable heritage asset across various regions. Geographically, these sites are concentrated in areas characterized by historical and climatic diversity, including the Middle East, North and West Africa, South Asia, and Latin America. This distribution underlines the adaptability and cultural resonance of adobe construction techniques in response to local environmental and societal needs. A notable point of concern is that some of these sites are currently listed as World Heritage in Danger. Specifically, sites located in countries such as Yemen (Shibam), Libya (Ghadamès), Mali (Djenné), Iraq (Ashur), and Afghanistan (Bamiyan Valley) are exposed to threats stemming from armed conflict, environmental degradation, or insufficient preservation efforts. In total, 7 out of the 28 sites are in danger, which highlights the fragility of adobe architecture and the urgent need for effective, context-sensitive conservation strategies.

All of these heritage values must be preserved and transmitted to future generations by meeting UNESCO's selection criteria and by maintaining their outstanding universal value, thus helping to bridge the past and the future. The specific selection criteria met by these 28 adobe-based World Heritage properties are presented in Table 3.

Table 3. Selection Criteria of Adobe Properties on the UNESCO World Heritage List

UNESCO World Heritage List	Criterion Description
Abu Mena	**Criterion IV:** Abu Mena is an exceptional early Christian monastic and pilgrimage center in the Near East, showcasing a blend of Egyptian and Mediterranean architectural influences.
Tchogha Zanbil	**Criterion III:** The ruins of Susa and Tchogha Zanbil are the only surviving examples of architectural development from the Middle Elamite period (1400-1100 BCE). **Criterion IV:** The ziggurat at Tchogha Zanbil is the best-preserved monument of its kind and the largest outside Mesopotamia.
Archaeological Ruins at Moenjodaro	**Criterion II:** Moenjodaro represents the earliest planned city in the Indian subcontinent, significantly influencing later urban developments. **Criterion III:** Moenjodaro, the best-preserved Indus Valley urban ruin from the 3rd millennium BC, provides exceptional testimony to the Indus civilization.

Table 3. continued

Old Walled City of Shibam	**Criterion III:** Shibam's dense multi-storeyed buildings with minimal ground-level openings reflect intense family rivalries and a long-standing homogeneous society, now threatened by socio-economic change. **Criterion IV:** Shibam, encircled by a fortified wall, is a prime example of Hadrami urban planning, with its grid layout and towering mudbrick houses, reflecting the city's economic and political prominence from the 16th to 19th centuries. **Criterion V:** Shibam, nestled between mountains and a floodplain wadi, is the last surviving evidence of a society adapted to spate agriculture, yet vulnerable to floods and socio-economic shifts.
Old Town of Ghadamès	**Criterion V:** Ghadamès is an exceptional Saharan settlement with a unique built heritage adapted to the harsh climate, serving as a key trans-Saharan trade hub for 2,000 years while developing distinctive architecture and traditions.
Bahla Fort	**Criterion IV:** Bahla Fort and its oasis settlement exemplify a defensive architectural ensemble that supported tribal prosperity in Oman and the Arabian Peninsula during the late medieval period.
Historic Centre of Lima	**Criterion IV:** The Historic Centre of Lima exemplifies Spanish colonial urban and architectural development in Latin America, showcasing adaptation to local materials, climate, and earthquakes. San Francisco de Lima is a remarkable and complete convent complex from the colonial era.
Old Towns of Djenné	**Criterion III:** Djenné-Djeno and associated sites provide exceptional evidence of pre-Islamic civilizations in the inland Niger Delta, showcasing evolving dwellings, industrial techniques, and rich archaeological finds. **Criterion IV:** Djenné's architecture, influenced by Moroccan and Toucouleur styles, exemplifies a significant historic period with vertical structures, buttressed facades, and the iconic 1906-1907 Mosque reconstruction.
Archaeological Sites of Bat, Al-Khutm and Al-Ayn	**Criterion III:** The settlements, necropolises, and workshop areas of Bat, al-Khutm, and al-Ayn form the most complete and well-known archaeological complex in Eastern Arabia from the 3rd millennium BCE. Cuneiform texts indicate that Magan (Oman) was a major copper extraction center, exporting to Mesopotamia and possibly the Indus Valley. The site provides evidence of increasing social hierarchy and economic changes due to long-distance trade. **Criterion IV:** The necropolis of Bat is a unique and characteristic testimony to the evolution of funerary practices during the Early Bronze Age in Oman.
Taos Pueblo	**Criterion IV:** Taos Pueblo is an outstanding pre-Hispanic architectural ensemble that has preserved its traditional forms due to the continuous living culture of its community.
Coro and its Port	**Criterion IV:** Coro and its Port showcase unique adobe architecture uncommon on the Caribbean Coast. Traditional mud-building techniques, such as bahareque, adobe, and tapia, have been adapted to social, climatic, and environmental conditions, forming a distinctive architectural style. **Criterion V:** Coro is an exceptional example of an early Spanish colonial town on the Caribbean coast of South America. It has preserved its original layout and urban landscape, combining Spanish, Mudéjar, and indigenous styles, later influenced by Dutch architectural elements from Curaçao and Aruba.
Archaeological Zone of Paquimé, Casas Grandes	**Criterion III:** Paquimé, Casas Grandes, serves as significant evidence of North America's cultural evolution, particularly highlighting pre-Hispanic trade and cultural exchanges. **Criterion IV:** The archaeological remains of Paquimé, Casas Grandes, showcase the evolution of adobe architecture in North America, demonstrating its fusion with advanced Mesoamerican techniques.
Tiwanakun Spiritual and Political Centre of the Tiwanaku Culture	**Criterion III:** The ruins of Tiwanaku provide remarkable evidence of the empire's influence in shaping the Andean pre-Hispanic civilization. **Criterion IV:** Tiwanaku's structures are outstanding examples of ceremonial and public architecture, representing a major Andean civilization.

Table 3. continued

Samarkand – Crossroad of Cultures	**Criterion I:** Samarkand's architecture and urban design, positioned at the crossroads of ancient cultures, exemplify masterpieces of Islamic cultural creativity. **Criterion II:** Architectural ensembles like Bibi Khanum Mosque and Registan Square significantly influenced Islamic architecture from the Mediterranean to the Indian subcontinent. **Criterion IV:** Samarkand's historic townscape reflects key phases of Central Asian cultural and political history from the 13th century to today.
Ashur (Qal'at Sherqat)	**Criterion III:** Ashur, founded in the 3rd millennium BC, was the first Assyrian capital and a key religious and political center, reflecting successive civilizations from Sumerians to the Parthian revival. **Criterion IV:** Ashur's remains illustrate the evolution of building practices from the Sumerian and Akkadian periods through the Assyrian empire and Parthian revival.
Cultural Landscape and Archaeological Remains of the Bamiyan Valley	**Criterion I:** The Buddha statues and cave art in Bamiyan Valley exemplify the Gandharan school of Buddhist art in Central Asia. **Criterion II:** The artistic and architectural remains of Bamiyan Valley reflect the interchange of Indian, Hellenistic, Roman, and Sasanian influences in Gandharan art, later influenced by Islam. **Criterion III:** Bamiyan Valley bears exceptional testimony to a vanished cultural tradition in Central Asia. **Criterion IV:** Bamiyan Valley is an outstanding example of a cultural landscape that illustrates a significant period in Buddhism. **Criterion VI:** Bamiyan Valley represents the most monumental expression of Western Buddhism and was a major pilgrimage site for centuries. Its monuments, including the destroyed Buddha statues, hold strong symbolic value.
Bam and its Cultural Landscape	**Criterion II:** Bam, located at the crossroads of key trade routes on the Iranian plateau, exemplifies the interaction of diverse cultural influences. **Criterion III:** Bam and its Cultural Landscape provide exceptional evidence of the development of a trading settlement in a desert environment in Central Asia. **Criterion IV:** Bam is an outstanding example of a fortified settlement and citadel in Central Asia, utilizing the chineh (mud layer) and khesht (mud brick) techniques. **Criterion V:** Bam's cultural landscape represents human-nature interaction in a desert environment, sustained by the qanat system, which is now vulnerable to change.
Pasargadae	**Criterion I:** Pasargadae is the earliest and most outstanding example of royal Achaemenid architecture. **Criterion II:** Built by Cyrus the Great with contributions from various peoples of his empire, Pasargadae marks a key phase in the evolution of classical Persian art and architecture. **Criterion III:** Pasargadae, with its palaces, gardens, and the tomb of Cyrus the Great, is an exceptional testimony to the Achaemenid civilization in Persia. **Criterion IV:** The "Four Gardens" royal ensemble in Pasargadae became a prototype for Western Asian architecture and landscape design.
Kunya-Urgench	**Criterion II:** The architectural tradition of Kunya-Urgench influenced Iran, Afghanistan, and later the Mughal Empire in India. **Criterion III:** Kunya-Urgench is a well-preserved testament to the Islamic culture of Khorezm, despite the disappearance of its original society.

Table 3. continued

At-Turaif District in ad-Dir'iyah	**Criterion IV:** At-Turaif Citadel represents a fortified urban ensemble in an oasis, showcasing the Najdi architectural style. It exemplifies an environment-adapted building method using adobe for palatial structures with geometric decoration. **Criterion V:** At-Turaif District in Ad-Dir'iyah illustrates a key phase of settlement on the Arabian plateau. In the mid-18th century, it became the capital of an independent Arab State and an important religious center, exemplifying human adaptation to the desert. **Criterion VI:** At-Turaif was the first historic center with unifying influence in the Arabian Peninsula. It played a key role in spreading the message of Salafiyya, influenced by Sheikh Mohammad Bin Abdul Wahhab's teachings and his alliance with the Saudi Dynasty in the 18th century.
Cultural Sites of Al Ain Hafit, Hili, Bidaa Bint Saud and Oases Areas)	**Criterion III:** The Cultural Sites of Al Ain showcase the evolution of prehistoric cultures in a desert region, documenting the transition from nomadic hunter societies to sedentary oasis settlements, demonstrating sustainable human development from the Neolithic to the Iron Age. **Criterion IV:** The tombs and architectural remains of the Hafit, Hili, and Umm an-Nar cultures illustrate human development during the Bronze and Iron Ages on the Arabian Peninsula. The aflaj system, introduced in the 1st millennium BC, exemplifies ancient desert water management techniques. **Criterion V:** The oases of Al Ain demonstrate the long-standing ability of civilizations in the northeastern Arabian Peninsula, particularly in protohistoric periods, to sustainably manage water resources and develop a fertile environment within the desert.
Historic Centre of Agadez	**Criterion II:** From the 15th century, Agadez became a major trans-Saharan trade hub, reflecting cultural exchanges through its unique mudbrick architecture, blending diverse stylistic influences within the Aïr region. **Criterion III:** Agadez's historic town features exceptional mudbrick architecture, including the Grand Mosque with its towering minaret and the Sultan's Palace. For over five centuries, it has preserved its cultural, commercial, and artisanal traditions.
Shahr-i Sokhta	**Criterion II:** Shahr-i Sokhta illustrates the transition from village life to urbanization, showcasing significant cultural, social, and economic advancements from the late Chalcolithic to early Bronze Age. **Criterion III:** Shahr-i Sokhta provides exceptional testimony to a civilization engaged in trade and cultural exchange with the Indus Plain, Persian Gulf, Oman Sea, and Central Asia. **Criterion IV:** Shahr-i Sokhta is an outstanding example of early urban planning, featuring mud-brick structures, burial grounds, workshops, and distinct functional zones.
Aqueduct of Padre Tembleque Hydraulic System	**Criterion I:** The Tepeyahualco aqueduct bridge is a unique architectural masterpiece with the tallest single-level arcade built from Roman times to the 16th century. Its innovative use of adobe formwork instead of scaffolding set it apart, making it an exceptional engineering achievement. **Criterion II:** The Padre Tembleque hydraulic system showcases a fusion of Roman masonry aqueduct traditions, Arab-Andalusian hydraulic techniques, and Mesoamerican collective labor practices. It embodies Franciscan humanist ideals through its innovative construction, reflecting cultural exchange and engineering excellence. **Criterion IV:** The Padre Tembleque aqueduct is an outstanding example of hydraulic architecture, combining Roman and Renaissance engineering with Mesoamerican construction techniques. Its use of regional materials and unique methods created an innovative hydraulic system.
Arslantepe Mound	**Criterion III:** Arslantepe offers exceptional evidence of early administrative elites during the Late Chalcolithic period, showcasing their societal role and relationship with the public. The site's well-preserved architectural and archaeological remains provide a detailed and rare insight into daily life, sealed by a sudden destruction event.

Table 3. continued

Sudanese style mosques in northern Côte d'Ivoire	**Criterion II:** The Sudanese-style mosques of northern Côte d'Ivoire illustrate cultural exchanges between the Gur and Mandé regions from the 14th to 18th centuries, blending Islamic and local architectural traditions. **Criterion IV:** These mosques exemplify architecture reflecting Islamic migration southward since the 14th century, symbolizing the spread of Islam and the fusion of Islamic and local styles.
Dholavira: a Harappan City	**Criterion III:** Dholavira is an exceptional example of a proto-historic Bronze Age urban settlement of the Harappan Civilization, showcasing a multi-cultural and stratified society from 3000 BCE to its decline. **Criterion IV:** Dholavira exemplifies Harappan urban planning with its structured city layout, multi-layered fortifications, advanced water reservoirs, drainage system, and extensive use of stone.
Royal Court of Tiébélé	**Criterion III:** The Royal Court of Tiébélé exemplifies Kasena culture through its unique adobe architecture, decorative style, and social-political significance, preserving its identity over time.

An examination of Table 3 reveals that the adobe heritage sites listed on the UNESCO World Heritage List reflect the historical, architectural, technological, and socio-economic development processes of various civilizations. These values are not merely physical structures; rather, they function as dynamic entities that embody past value systems, forms of cultural interaction, and human-environment relationships. In this context, urban settlements, regionally interpreted architectural styles, spaces serving as religious and political centers, and cultural landscapes that reflect sustainable ways of living are particularly noteworthy. Moreover, monumental structures constructed using unique building techniques provide evidence of both technological advancement and the utilization of local materials. These findings indicate that heritage sites are not only witnesses to the past but also serve as significant reference points for understanding cultural continuity and diversity.

Table 4. The Authenticity of Adobe Properties on the UNESCO World Heritage List

UNESCO World Heritage List	Authenticity
Abu Mena	The authenticity of the monastery is based on the preservation of its overall design, buildings, and original construction materials. Although few structures remain completely intact, ground plans and some vertical elements have been preserved. The large basilica, churches, and industrial remains demonstrate the region's structural and technological development during the 4th century.
Tchogha Zanbil	Despite conservation efforts, the historical monuments of Tchogha Zanbil have largely retained their authenticity in terms of form, material, and location.
Archaeological Ruins at Moenjodaro	Moenjodaro, one of the earliest urban centers of the Indus civilization, has preserved its authenticity through its baked brick structures and city planning; however, it is endangered due to environmental developments.
Old Walled City of Shibam	While Shibam has maintained its authentic elements reflecting traditional lifestyles and architecture, the tendency toward concrete construction and external factors pose a threat to its authenticity.
Old Town of Ghadamès	The Old Town of Ghadamès has preserved its authentic character without interventions in the design and materials of its buildings. Although its residents no longer live there permanently, they continue to utilize the old town. The city features a unique architecture with high parapeted roofs, enclosed alleyways, and traditional construction materials. Traditional building techniques have been preserved, and water management and cultural practices have continued. Throughout history, the city has served as an important trade center and contains valuable manuscripts providing insights into its past.
Bahla Fort	Bahla Fort was included in the List of World Heritage in Danger in 1988 due to rapid deterioration but was removed from the list following restoration efforts in 2004. Although some inappropriate interventions occurred during the 1990s, since 1995, efforts have focused on preserving the original structure using mudbrick-based materials. The abandonment of traditional houses and lack of preservation of the marketplace are the main threats to the site's authenticity.

Table 4. continued

Historic Centre of Lima	The Historic Centre of Lima has largely preserved its original urban layout and historic expansion areas. Public, private, and religious structures reflect European architectural influences while also adapting to the region's natural and social conditions. The city's traditional way of life strengthens the authenticity and identity of the center. However, threats such as earthquakes, real estate speculation, and informal commerce necessitate strict regulations to preserve its authenticity.
Old Towns of Djenné	Djenné's authenticity is ensured through its well-preserved adobe construction materials and the continuation of traditional building techniques passed down through generations. The city retains its identity as a "devout city," characterized by the Great Mosque and its cultural values.
Archaeological Sites of Bat, Al-Khutm and Al-Ayn	Bat and its surroundings form an ancient site that has maintained its authenticity through monumental towers, tombs, and irrigation systems. The tombs have been reused over time, sustaining their functional significance.
Taos Pueblo	Taos Pueblo has preserved its authenticity in terms of location, design, materials, and cultural functions. The community continues to use traditional construction techniques and maintain their traditional lifestyle. Modern elements have remained limited, and electricity and water installations are prohibited within the walled area. Nevertheless, factors such as town expansion, tourism, airport expansion plans, and environmental threats pose risks to its authenticity.
Coro and its Port	The urban layout of Coro and its traditional adobe construction system have been preserved to the present day. The city maintains the irregular block pattern reflecting Spanish influence. While the spatial and structural characteristics of the buildings have been preserved, traditional building techniques continue to be employed today. This continuity reflects the historical spirit and development of the site.
Archaeological Zone of Paquimé, Casas Grandes	Paquimé is a significant archaeological site that has largely avoided large-scale changes, preserving its authenticity. Conservation efforts have been limited to applying original adobe materials as protective coatings, aiming to maintain the site's physical integrity. The region's authenticity is tied to the cultural heritage of the Grande and Colorado river peoples, and this influence is evident in architectural features such as T-shaped designs and porticoed facades.
Tiwanakun Spiritual and Political Centre of the Tiwanaku Culture	Tiwanaku is an archaeological site that has retained a high degree of authenticity. However, a detailed conservation plan is essential to sustain this authenticity.
Samarkand – Crossroad of Cultures	Although the historical fabric of Samarkand and Afrasiyab has been preserved, the construction of modern buildings and changes within private properties pose threats to their authenticity.
Ashur (Qal'at Sherqat)	Ashur has remained uninhabited since the 2nd century BCE, which has enabled the preservation of its remains' authenticity. The site's historical structure has remained largely intact, with only an Ottoman-era barracks and an excavation house constructed later. Restoration efforts carried out in the 1980s were conducted using traditional materials and techniques.
Cultural Landscape and Archaeological Remains of the Bamiyan Valley	The Bamiyan Valley retains the traces of the past through its cultural and archaeological remains. While the site has preserved its authenticity through traditional structures and land use, it is at risk due to modern developments and requires a carefully managed conservation process.
Bam and its Cultural Landscape	The site has largely maintained its authenticity thanks to restorations conducted with traditional materials and techniques. Although some modern restorations were damaged during the 2003 earthquake, original materials have remained well-preserved. The culture of adobe architecture, urban layout, and traditional craftsmanship continue. It is crucial that restorations are carried out in accordance with international principles to sustain authenticity and to ensure the continuation of historical practices.

Table 4. continued

Pasargadae	Pasargadae has been preserved in its original location and structure, remaining unaffected by modern interventions. Recent restorations have been undertaken using traditional methods, fully maintaining the historical fabric of the site.
Kunya-Urgench	The site continues to function as a religious center and pilgrimage site, thus preserving its overall authenticity. The main monuments have retained much of their original materials and possess a reasonable degree of authenticity. Some structures have been partially reconstructed to prevent complete collapse. Overall, the principal monuments have largely maintained their original character.
At-Turaif District in ad-Dir'iyah	The site's authenticity is preserved through components that have neither been altered nor reconstructed. Although the structures remain in a ruined state, a restoration program faithful to the original plans is being implemented. A careful conservation approach must be prioritized to maintain the site's authenticity.
Cultural Sites of Al Ain Hafit, Hili, Bidaa Bint Saud and Oases Areas)	The prehistoric sites of Al Ain largely retain their authenticity; however, the partial reconstruction of some circular tombs limits this authenticity. Iron Age irrigation systems, such as the Hili 15 falaj, have survived intact but have been subject to later additions. While early restorations of the oases since the 1980s focused on reconstruction, recent efforts have emphasized the importance of authenticity. Local governments and farmers are making efforts to sustain the oases, though these processes must be carefully monitored due to economic and environmental pressures.
Historic Centre of Agadez	Although the monuments and palaces generally preserve their authenticity, the use of modern materials in window and door frames negatively impacts their original character. Similarly, residential buildings face threats from the use of non-traditional materials such as cement, metal, and modern blocks, as well as from aggressive advertising in vivid colors, all of which compromise the aesthetic and historical fabric.
Shahr-i Sokhta	The desert landscape of Shahr-i Sokhta, along with its surface archaeological remains and complex architecture, strongly reflects the site's preserved authenticity.
Aqueduct of Padre Tembleque Hydraulic System	The physical components of the hydraulic system have maintained their traditional structures and thus their authenticity. A six-kilometer section in Zempoala continues to function in water transportation, while the extension toward Otumba is planned to be revitalized. This process must be supervised by heritage experts. Local communities contribute to the conservation of the system through maintenance and repairs using traditional techniques. Particularly, the glyphs on the aqueducts reveal the collaborative construction efforts between indigenous peoples and Spanish clergy.
Arslantepe Mound	At Arslantepe, the structures—particularly the palace complex—are entirely authentic, with no reconstruction efforts undertaken. The adobe walls, plasters, wall paintings, and floors have been preserved in their excavated state. Minor repairs have been made using only original materials. The roofing system has been designed not to damage the archaeological layers. The palace complex and the surrounding landscape remain unaltered, with excavation findings providing insight into the region's artistic and cultural production capacities.
Sudanese style mosques in northern Côte d'Ivoire	The eight mosques in northern Côte d'Ivoire have largely preserved their authenticity through their architectural forms, traditional building materials, and techniques. The Sudanese-style architecture is sustained with local materials and the continued presence of traditional craftsmen. Although modern mosques have been constructed, the traditional ones are still actively used for worship and social activities. However, the continued authenticity of these mosques depends on community support and the availability of local craftsmen.

Table 4. continued

Dholavira: a Harappan City	Dholavira exhibits a systematic urban layout with fortifications, gates, water systems, and workshops, all reflective of Harappan culture. Structures have been preserved in situ using scientific conservation methods to maintain their authenticity. Excavations have revealed the city's architectural features and planning, which are well preserved due to the use of stone and adobe materials.
Royal Court of Tiébélé	The Royal Court of Tiébélé has largely preserved the architectural and traditional practices distinctive to the Kasena culture. The maintenance of traditional motifs and the creation of new ones will further strengthen the cultural continuity of the site. Nevertheless, the increasing use of modern construction materials may threaten the property's authenticity.

An analysis of Table 4 reveals that the majority of adobe-based cultural heritage sites inscribed on the UNESCO World Heritage List have largely retained their authenticity in terms of construction materials, building techniques, spatial organization, and functional continuity. This preservation is primarily attributed to the continued use of traditional methods and materials, the limitation of modern interventions, and the sustained cultural practices of local communities.

3. Results and Discussion

Among the main factors contributing to the deterioration of adobe materials, which have been used as building materials throughout history, water plays a primary role. This includes rainwater, capillary rise from the ground, and faulty or insufficient drainage. In addition, temperature fluctuations (such as high humidity levels and extreme temperature changes), as well as biological and anthropogenic factors—such as vegetation, animals, and human activities—also significantly contribute to the degradation of adobe structures (Ashurst, 1990; Orbaşlı, 2008; Zakar & Eyüpgiller, 2015). These factors, whether acting independently or in combination, can lead to the disintegration of the wall mass, causing partial or complete collapse, or result in vertical misalignment and deformation of the wall plane. Common forms of deterioration observed in adobe walls include superficial and structural cracks, cavities, and perforations (Zakar & Eyüpgiller, 2015). Natural phenomena such as excessive rainfall, temperature fluctuations, and drought—arising from climate change—inevitably cause damage to heritage sites constructed with adobe materials. Table 5 presents the climatic events affecting adobe heritage sites inscribed on the UNESCO World Heritage List, the resulting forms of deterioration, and the corresponding preventive or remedial measures taken.

Table 5. Climate Change Impacts, Observed Damages, Preventive Measures, and Interventions on UNESCO World Heritage List

UNESCO World Heritage List	Climate Change	Damages	Measures
Abu Mena	Rise in groundwater levels	Structural collapses and foundation deterioration	Groundwater control and structural reinforcements
Tchogha Zanbil	Intense precipitation and drought	Erosion, subsidence, and surface abrasion	Protective roofing, drainage systems, and digital monitoring
Archaeological Ruins at Moenjodaro	Flooding and temperature fluctuations	Cracking, surface disintegration, and abrasion	Waterproofing, temporary coverings, and local conservation planning
Old Walled City of Shibam	Heavy rainfall and flooding	Structural failures, plaster detachment, and foundational decay	Structural bracing and temporary roof systems
Old Town of Ghadamès	Extreme temperature and drought	Cracks, plaster detachment, and moisture damage	Localized repairs and traditional heat-mitigation techniques
Bahla Fort	Heavy rainfall and thermal variation	Erosion, settlement, and timber decay	Structural reinforcement, adobe repair, and visitor restrictions
Historic Centre of Lima	El Niño events and heavy rainfall	Decay, plaster loss, and ground subsidence	Wall repairs, drainage implementation, and protection strategies

Table 5. continued

Old Towns of Djenné	Sudden rainfall and thermal variation	Erosion, decay, and dome deterioration	Traditional plastering rituals, monitoring, and flood protection
Archaeological Sites of Bat, Al-Khutm and Al-Ayn	Heavy rainfall	Erosion and stone displacement	Stone wall reinforcement and rainwater drainage
Taos Pueblo	Drought, sudden rainfall	Cracks and plaster flaking	Adobe restoration using traditional methods
Coro and its Port	Rainstorms	Surface abrasion and wall collapses	Drainage systems and adobe surface renewal
Archaeological Zone of Paquimé, Casas Grandes	Temperature fluctuation	Surface cracking and spalling	Restoration and application of climate-resilient materials
Tiwanakun Spiritual and Political Centre of the Tiwanaku Culture	Heavy rainfall	Ground deformation and structural shifting	Rainwater drainage and structural reinforcement
Samarkand – Crossroad of Cultures	Freeze–thaw cycles	Ceramic loss and wall cracking	Thermal insulation and ceramic restoration
Ashur (Qal'at Sherqat)	River flooding	Erosion	Dam planning and site protection measures
Cultural Landscape and Archaeological Remains of the Bamiyan Valley	Freeze–thaw action and rainfall	Surface flaking	Rock stabilization and microclimate control
Bam and its Cultural Landscape	Post-seismic climatic impacts	Subsidence and moisture damage	Reconstruction and enhanced climate resilience
Pasargadae	Extreme temperature and drought	Stone deterioration	Application of surface protective coatings
Kunya-Urgench	Increased soil moisture	Wall swelling and cracking	Ground drainage and brick repair
At-Turaif District in ad-Dir'iyah	Sandstorms and drought	Abrasion and surface loss	Restoration and sand control measure
Cultural Sites of Al Ain Hafit, Hili, Bidaa Bint Saud and Oases Areas)	Extreme temperature	Cracking	Climate-adaptive repairs
Historic Centre of Agadez	Sandstorms	Surface deterioration	Adobe restoration
Shahr-i Sokhta	Extreme temperature	Cracking and flaking	Preventive measures and roof coverings
Aqueduct of Padre Tembleque Hydraulic System	Thermal fluctuation	Stone erosion	Stone reinforcement
Arslantepe Mound	Rainfall	Erosion	Protective roofing and adobe repair
Sudanese style mosques in northern Côte d'Ivoire	Rainfall and thermal variation	Surface abrasion	Localized repairs
Dholavira: a Harappan City	Flood and drought	Stone displacement	Water management systems
Royal Court of Tiébélé	Rainfall	Paint fading and surface deterioration	Traditional painting and protective coatings

Table 5 systematically illustrates how cultural heritage sites, primarily constructed using adobe building technologies, inscribed on the UNESCO World Heritage List, are affected by climate change. The data detail the climatic threats encountered by each site, the resulting physical damages, and the implemented or proposed conservation measures. The table highlights the regional variability of climate change impacts, emphasizing the significance of each site's geographic and climatic context. It is evident that adobe materials are particularly vulnerable to moisture and thermal fluctuations, often resulting in rapid and irreversible deterioration. The conservation responses indicate the application of systematic and adaptive approaches tailored to the specific vulnerabilities of these heritage structures.

4. Conclusions

For heritage properties to be inscribed on the UNESCO World Heritage List, they must meet one or more of the selection criteria established by UNESCO. Among the adobe (adobe) heritage properties that have been inscribed on the World Heritage List by fulfilling these criteria, several have suffered damage due to climate-related changes—particularly from extreme rainfall and significant temperature fluctuations. This study investigates the types of damages observed, the conservation measures taken, and the intervention methods applied to safeguard these properties. Based on the findings, it is understood that seven of the listed adobe heritage properties are currently at risk of disappearance. Therefore, it is crucial to ensure their protection and survival, as well as to conserve other adobe heritage sites that are not yet listed but reflect the historical and cultural narratives of their respective countries.

In light of this study, the following conservation strategies and intervention techniques are proposed for adobe heritage structures affected by climatic phenomena:

- Development of drainage systems to protect against rising groundwater.
- Installation of protective roofs to guard against heavy rainfall.
- Construction of temporary shelter structures.
- Reproduction of deteriorated adobe materials using traditional construction methods.
- Structural reinforcement of weakened adobe wall systems using support elements.
- Application of surface coatings to prevent further deterioration of the adobe material following interventions.

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Revitalization and integration of historic city walls and castles into the urban fabric: A comparative analysis

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Abstract. Anatolia has hosted various civilizations throughout history, making it a geographically diverse region that bears the traces of these cultural formations. The cities within this region stand out not only for their historical structures but also for the social, cultural, and economic dynamics that have evolved around them. In particular, historic city walls and castles have played significant roles as both defensive structures and cultural symbols throughout different historical periods. However, natural disasters, improper urban planning, and rapid urbanization have made the preservation of these structures and their transmission to future generations increasingly challenging. In this context, the conservation of historic city walls and castles is not only an architectural concern but also a social and cultural responsibility. This study aims to examine the preservation status, restoration efforts, and adaptive reuse strategies of historic city walls and castles surrounding the historic city centers of ten different cities in Anatolia from a comparative perspective. Through literature reviews supported by historical, architectural, and archaeological data, as well as as comparative analysis methods, the transformations of these castles over time and their integration processes into contemporary urban fabrics have been thoroughly analyzed. The research highlights the challenges encountered in preserving the architectural and cultural values of historic castles and city walls. In this context, it draws attention to core problems such as restorations and repairs carried out throughout the life cycle of these structures, improper urban planning practices and their impact on historic walls and castles, adaptive reuse cases, and the difficulties in integrating their original functions into modern life.

Keywords: Urban Conservation; Restoration; Castle and City Wall Structures; Adaptive Reuse; Cultural Heritage

1. Introduction

Anatolia has been home to many civilizations throughout history and has a rich heritage bearing the traces of the cultural formations of these civilizations. Historical fortifications and castles, one of the most important elements that determine urban identity, have functioned not only as defensive structures but also as elements that shape the cultural, architectural and social dynamics of the cities in which they are located (Algharibi, 2024). While these structures reflect the defense strategies and administrative structures of cities, they also reveal the spatial organization of settlements, their relationship with trade networks and social memory. However, natural disasters, wrong zoning practices and rapid urbanization threaten the physical integrity of these structures and lead to radical changes in urban morphology (Özkaynak, 2023).

In this transformation process, how to integrate historical fortifications and castles into the modern urban fabric has become one of the main research areas of conservation policies. These structures should be preserved and integrated into urban life not only for their physical presence but also for their historical, cultural and artistic values (Tan, 2014). However, conservation policies and practices vary across countries due to differences in legal frameworks, planning strategies and implementation processes. In Turkey, although the Law No. 2863 on the Protection of Cultural and Natural Assets constitutes the basic legal infrastructure for the protection of urban heritage, local governments need to take more effective decisions to integrate these structures into modern urban life (Bahçeci Başarmak, 2022).

International examples reveal that different models have been implemented for the conservation and re-functionalization of historic walls and castles. In cities with largely preserved fortifications, such as Italy, fortifications are integrated with pedestrian paths, cultural spaces and green areas and positioned as an active component within the city (Naiboğlu, 2019). Such examples constitute an important reference for developing sustainable conservation models for fortified cities in Anatolia.

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In this context, this study aims to examine the conservation processes, restoration practices and integration models of the historic walls and castles surrounding the historical city centers of 10 different cities in Anatolia from a comparative perspective. Using a comprehensive comparative analysis method supported by historical, architectural and archaeological data, the study will examine in detail the transformations of these structures from past to present, their relationship with urban planning and their adaptation processes based on conservation policies. In addition, the role of local governments, the effectiveness of existing legal regulations and the impact of social awareness on these processes will be evaluated and assessments will be made in the context of sustainable conservation and integration models. The main aim of the study is to develop sustainable and integrated conservation policies for the preservation of historical fortifications in Anatolia and to propose new strategies on how these structures can be incorporated into modern urban life.

2. Materials and Methods

This study aims to provide a comprehensive assessment of the conservation and integration of historical fortifications and castles in Anatolia into the modern urban fabric. The methods used within the scope of the study are discussed under three main headings by adopting an interdisciplinary approach. Within this framework, firstly, literature research was conducted on national and international academic studies, declarations and legal regulations on the conservation, restoration processes and re-functionalization of historical buildings. In this context, the practices carried out within the framework of the Law No. 2863 on the Protection of Cultural and Natural Heritage and UNESCO's principles for sustainable conservation practices of cultural heritage were also taken into consideration. In the second stage of the research, 10 cities with historical fortifications and castles in Anatolia included in the scope of the study and the conservation, restoration and re-functioning processes carried out in these cities were analyzed comparatively. In this context, the physical conditions of historical castles and fortifications, the restorations they have undergone, their level of integration with the modern urban fabric and the conservation problems encountered were evaluated, and the success potentials of conservation practices were evaluated together with their positive and negative aspects. In the third part of the study, spatial and structural analyzes are discussed. In this framework, the basic analytical method was used to examine the spatial organization and structural conditions of the historic walls and castles, and evaluations were made through urban morphology analysis. In this context, in order to evaluate the relationship of historical buildings with the urban fabric, spatial sequence analyses were used to examine the impact of fortifications and castles on urban mobility, their transformation in the spatial context and their accessibility within the city. In line with the data obtained, sustainable strategies for the protection and integration of historical fortifications in Anatolia into urban life were evaluated. In this context; conservation of historical castles and fortifications as cultural heritage, functional transformation proposals compatible with urban planning, development of holistic management models, sustainable tourism and economic benefit creation approaches have been discussed.

3. Conservation, Urban Conservation, Restoration and Reuse

Cultural Assets, which are related to science, culture, religion and fine arts belonging to historical periods or which have been the subject of social life in prehistoric or historical periods and which have unique scientific and cultural value, vary from the scale of movable objects to the urban scale. It is important in terms of cultural, social and economic sustainability that individual buildings, cities and urban ruins, which are the products of various civilizations from prehistoric times to the present day, reflecting the social, cultural, economic, architectural and similar characteristics of the periods they lived in, are protected and transferred to future generations. The sustainability of cultural heritage can be ensured by the concepts of time, continuity, protection and co-existence with change. Conservation, which is defined as the preservation of cultural heritage in order to transfer past values to future generations, is an important responsibility of today's societies. The Concept of Conservation is defined within the scope of the Law No. 2863 on the Protection of Cultural and Natural Heritage; within the framework of conservation, maintenance, repair, restoration and function change operations of immovable cultural and natural assets. In the context of the Concept of Conservation, in accordance with the relevant Law, conservation zoning plans based on field research, including archaeological, historical, natural, architectural, demographic, cultural, socio-economic, property and construction data, are prepared in order to protect cultural and natural assets in line with the principle of sustainability, taking into account the interaction-transition area of the area. Socio-cultural and historical data, which have an important place in urban planning data, have a key importance in the formation of multi-layered historical city models. In this context, while preparing Conservation Zoning Plans, area management models are used in accordance with principles such as conservation principles and use and building restrictions, sanitization, renovation areas and projects, open space system, pedestrian circulation and vehicle transportation, design principles of facilities, densities, parcel designs, local ownership, etc. (Algharibi, 2024; Başarmak, 2022).

Reuse practices developed for the continuity of the existence of historical buildings, which have become obsolete and idle due to various reasons over time, by adapting to today's conditions, have the potential to be beneficial in many ways to the three components of sustainable development (social, environmental, economic).

It contributes to environmental balance as it reduces energy and resource use by preserving the existing building stock; to sociocultural development by maintaining cultural values through the preservation of historic buildings; and to economic development by eliminating the cost of building a new structure and increasing the asset value of the region by improving the building and its surroundings. The main challenge of reuse is to find the most appropriate new function that does not compromise the principles of conservation and the values of historic buildings, while at the same time contributing to development. The success of the new function is about balancing these opportunities and challenges. Due to the negative effects of rapid urbanization and population growth, technological and military developments, Defense Buildings, which have lost their original function despite their historical value and importance, are among the most important Cultural Assets that affect the urban scale and planning decisions in this context. Castles and fortifications used for public defense in the historical process have been replaced by underground shelters due to the mobility of modern weapons. In the historical process, defensive structures such as castles, fortifications, etc., which were built to protect cities and living spaces, including building communities, from external influences, have remained in a dysfunctional position due to the development of modern defense methods in technological and military terms and the change of war strategies. Historical walls and castles are important structures reflecting the architectural, military and cultural heritage of past civilizations. However, the protection and preservation of these structures is of great importance due to the loss of their functions over time, natural wear and man-made destruction. Historical walls and fortresses, which are considered among the most important heritage in many cultures around the world, include the Great Wall of China, known as the world's longest defensive wall; the Walls of Istanbul (Turkey), dating from the Byzantine period, such as the Walls of Theodosius and the Walls of Constantine; the Walls of Diyarbakır (Turkey), dating from the Roman period, which is on the UNESCO World Heritage ; the Walls of Carcassonne (France), known as a perfectly preserved walled city from the Middle Ages; and the Walls of Avignon (France), which stands out among the historical walls during the Papal period; Examples include the Harran Walls (Turkey), known as a historical fortification system from ancient Mesopotamia; the York City Walls (England), dating back to the Roman period and extended in the Middle Ages; the Krak des Chevaliers Walls (Syria), a castle and fortification complex from the Crusader period; the Great Zimbabwe Wall (Zimbabwe), an African fortification system of stone; and the Trojan Walls (Turkey), the legendary defensive walls of the ancient city of Troy. (Yolcu,2023; Algharibi,2024; Başarmak,2022; Naiboğlu,2019)

Today, the adaptive reuse of these important historical buildings to contemporary needs plays a critical role in terms of both the protection of cultural heritage and tourism and urban development. International restoration principles (such as the Venice Charter, Burra Charter) should be taken as a guide for the conservation of historic walls and castles. In line with these principles; the use of original materials and techniques, structural reinforcement and stabilization, archaeological and historical analysis, and the principle of minimal intervention come to the fore. In the context of the use of original materials and techniques; it is essential to preserve the original materials and use new materials with similar properties. Traditional construction techniques should be applied without disturbing the historic fabric of the building. In the context of structural strengthening and stabilization; modern engineering solutions (carbon fiber reinforcement, steel supports, etc.) should be applied to strengthen the structural systems that have weakened over time without disturbing the original fabric. Archaeological and historical analysis includes detailed documentation, archaeological excavations and historical research to understand the original form of the building before restoration. Intervening as little as possible, preserving the original elements and avoiding unnecessary additions are considered in the context of the principle of minimal intervention. When the issue is evaluated in the context of sustainable conservation principles, it is seen that the preservation of the relevant structures and their adaptation to today's comfort conditions and their transfer to future generations is only possible through reuse. In particular, defensive structures that have lost their original function, such as castles and fortifications, can be used as cultural and art centers with functions such as concert halls, exhibition areas or open-air theaters by developing functional transformation projects; as museums and historical parks by creating interactive museums or archaeoparks reflecting the military past of the structures; As education and research centers that can host history and architecture studies in cooperation with universities or cultural institutes; reuse for tourism purposes with the use of boutique hotels, luxury accommodation and gastronomy facilities that do not disrupt the historical texture are considered as functional suggestions that can ensure that the relevant buildings that have lost their original function in the literature can hold on to the vital cycle (Yolcu, 2023).

4. Historical Castles, Fortifications and Their Relationship with the City

Castle; It is defined as a defense structure built to hold a land, land, a geographical place and to ensure its security. They are structures built for defense purposes on the roads where the arrival of the enemy is expected, in cities of strategic importance, passages and bottlenecks, in a position to dominate the region in which it is located. It has entered the architectural literature as defensive structures consisting of thick and high walls with battlements, towers and fortifications built to defend a certain area. Such fortifications have been used since antiquity and served as administrative, political and economic centers in addition to their military functions. Some castles provided accommodation for the people of the palace. It defines a whole settlement in itself with service structures in which people can stay permanently and meet their daily vital . Defensive structures and settlements such as castles and fortifications are purpose-designed structures, regardless of their size. Formation and spatial organization are directly oriented towards function. It is seen that fortress structures generally consist of sections with different characteristics such as inner castle, outer castle, city hall, rabat, tower (inner / outer) / head tower, gate tower, poterna, fortification wall / curtain wall, rampart, battlements, battlements with battlements, arrow battlements, moat, etc. The inner castle is defined as the last defense located at the highest point or the center of a walled city, where the administrative level and/or the city's dignitaries are located; the şehristan is the section where the commercial and residential areas, religious and public buildings, which constitute the main part of the city, are located; and the rabat isthe functions and structures related to trade, which are mostly outside the walls and around the castle gates, are located. The castle square, on the other hand, defines the large areas in the center of the castle where soldiers gather and train. The preservation of the architectural and historical integrity of castles, city walls and surrounding settlements, which are important structures of urban identity, is only possible if the relationship between these structures and the city can be fully analyzed. For example, when castles and city walls are evaluated morphologically; it is known that castles and city walls were built as outer fortresses and adjacent to residential areas for defense purposes in ancient times. In the Greek and Hellenic periods, there were city walls surrounding the cities; in the Roman period, walled cities were replaced by single castle structures or walled castle settlements; in the Byzantine period, due to the decrease in the security environment in the settlements, walls were built for protection surrounding the city centers again, and for this reason, it is understood from the literature that Byzantine cities were depicted as castle-cities (castron). Within the scope of the study, 10 different cities (Kayseri Castle, Erzurum Castle, Amasya Castle, Van Castle, Tokat Castle, Trabzon Castle, Istanbul Rumeli Fortress, Konya Castle, Sivas Castle, Antalya Castle) located in different regions of Anatolia with historical walls and castles and the conservation, restoration and re-functioning processes carried out in these cities were evaluated comparatively.

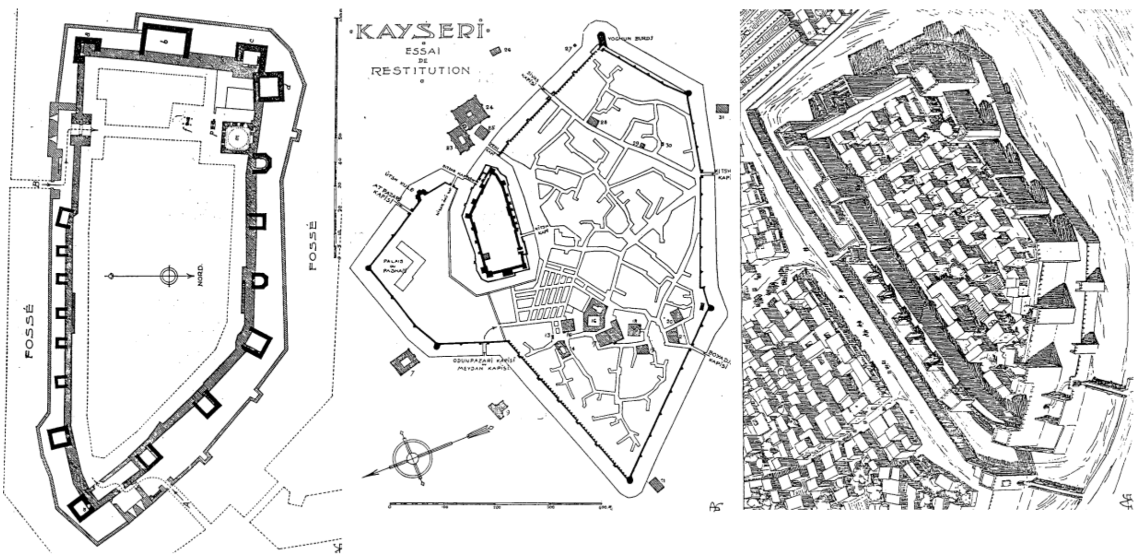

Fig. 1. Plan of Kayseri Castle (İnbaşı, 2003).

Table 1. Kayseri Castle Analysis Table

Name of Structure	Kayseri Castle
Location	Kayseri province, Melikgazi district, city center, around Cumhuriyet Square. (Akok, 1964; Güner, 2021)
Construction Date / Period	Roman Period, 238-244 AD, reign of Emperor Gordianus III. (Yolcu, 2023;İnbaşı, 2006)
Producer / Produced by	Roman Emperor Gordianus III (Passenger, 2023).
History of the Building	It was built as a military base during the Roman period and was repaired during the Byzantine and Seljuk periods. During the Ottoman period, it lost its military function and was opened to civilian settlement and trade. (İnbaşı, 2006; Yolcu2023Güner, 2021)
Architectural Features	The citadel is adefense system surrounded by bastions opening in four directions. The bastions have three to four floors. Wall roads, battlements and vaulted spaces are noteworthy. (Akok, 1964)

Table 1. continued

Materials and Construction Techniques	Cut stone, rubble stone, lime mortar, wood, reed and iron were used. These materials were also documented in Ottoman repairs (İnbaşı, 2006; Akok, 1964).
Changes Over Time	It underwent major repairs in 1507 and 1553. In the 20th century, it was used for commercial purposes, and a reinforced concrete bazaar was built in 1987. After the 2008 competition, the re-functioning process was initiated (Güner, 2021; İnbaşı, 2006).
Conservation Status and Challenges	Restoration practices have emphasized commercial and touristic use, and conservation principles have been violated from time to time (Güner, 2021).
Current Usage	Cultural activity area and commercial units. There are shops and temporary exhibition within the Inner Castle (Güner, 2021).
Potential for Reuse	The castle has the potential to be integrated into urban life while preserving its cultural heritage identity (Akok, 1964).
Place in the Urban Fabric and Integration Status	While in the 19th century it had more widespread connectivity, today its physical integration with new streets has increased (Yolcu, 2023).
Evaluation and Recommendations	Re-functionalization processes should be planned in line with conservation principles, and economic-oriented interventions should not damage cultural identity. Pedestrian connections should be strengthened (Güner, 2021; Yolcu, 2023).

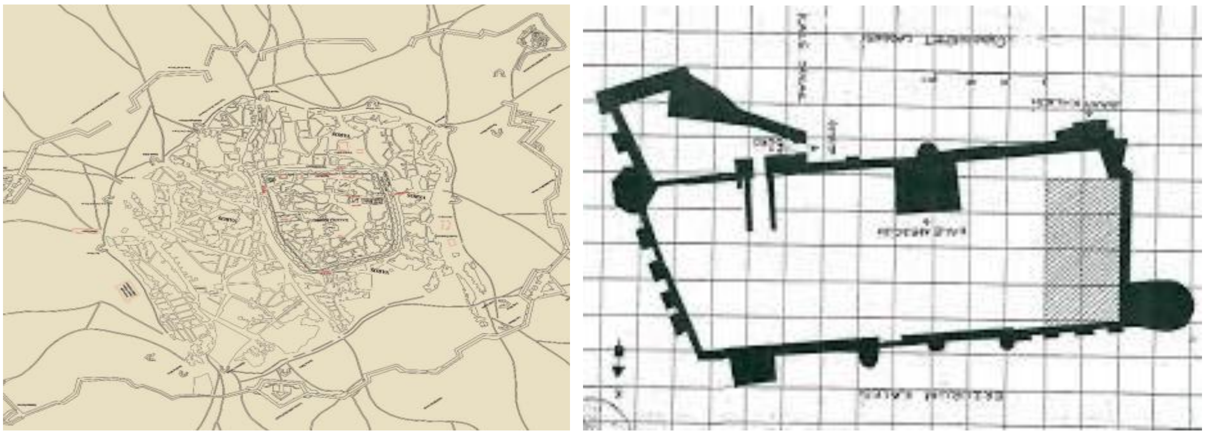

Fig. 2. Erzurum Castle, Walls, Bastions and Erzurum Castle Plan (Küçükuğurlu, 2017; URL-3).

Table 2. Erzurum Castle Analysis Table

Name of Structure	Erzurum Castle
Location	Erzurum province is located on the northern slopes of the Palandöken Mountains at the highest point of the city center (Gündoğdu, 2016).
Construction Date / Period	It was built between 415-420 AD by the Eastern Roman Emperor Theodosius II (Gündoğdu, 2016).
Producer / Produced by	Eastern Roman (Byzantine) Emperor Theodosius II (Gündoğdu, 2016).
History of the Building	First established as a military garrison, it was strengthened with various fortifications during the Byzantine, Saltuklu, Seljuk, Mongol and periods (Solmaz, 2013; Küçükuğurlu, 2010).
Architectural Features	The citadel is approximately 50x130 m, surrounded by 2-2.5 m thick walls; the bastions are square, octagonal and polygonal in plan (Gündoğdu, 2016).
Materials and Construction Techniques	Cut stone, rubble stone, brick, lime mortar, walnut and hornbeam wood, cast iron were used (Demlikoğlu, 2022).
Changes Over Time	Bastions were added in the 18th-19th century, and in the 20th century the wall stones were used in public buildings; the Outer Fortress was destroyed (Küçükuğurlu, 2010).
Conservation Status and Challenges	Although it is a 1st degree archaeological site, its surroundings have been transformed with modern buildings and 12% of the traditional texture has disappeared (Atabeyoğlu et al., 2009).
Current Usage	Within the scope of the Kültür Yolu Project, it was reorganized as an open public space and became a part of social life (Kokarca & Batuhan, 2022).

Table 2. continued

Potential for Reuse	Cultural routes have the potential to be integrated into urban memory through open-air museums and functional transformations (Kokarca & Batuhan, 2022; Demlikoğlu, 2022).
Place in the Urban Fabric and Integration Status	Historically, the development of the city was shaped around the castle and transformed into transportation axes with the Jacques Lambert Plan of 1938 (Küçükuğurlu, 2010).
Evaluation and Recommendations	Conservation should be planned on a holistic, physical, social and environmental level; public participation should be ensured and cultural memory should be preserved (Atabeyoğlu et al., 2009; Küçükuğurlu, 2010).

Table 3. Amasya Castle Analysis Table

Name of Structure	Amasya Castle (Harşena Castle)
Location	The province of Amasya is located on the northern slope of Yeşilırmak on the summit of Mount Harşena (Karabağ, 2022; TÜBA-AR, 2021; Amasya Municipality (n.d.)).
Construction Date / Period	The first structures date to the Hellenistic period (3rd century BC); they were built by the Pontic Kingdom (Karabağ, 2022; TÜBA-AR, 2021; Amasya Municipality (n.d.)).
Producer / Produced by	During the reign of Pontic King Mithradates I (301-266 BC), the castle was built as the capital (Karabağ, 2022; Amasya Municipality (n.d.)).
History of the Building	The castle was used during the Roman, Byzantine, Danishmendli, Seljuk, Eretnalı and Ottoman periods and developed with various repairs and additional structures in each period (Canıbek, 2020; Karabağ, 2022; TÜBA-AR, 2021; Amasya Municipality (n.d.)).
Architectural Features	The castle consists of three sections; Upper Castle, Kızlar Sarayı Mevkii and Lower Castle. The walls are square and rectangular in plan, in harmony with the natural topography. The King's Tombs stand out with their monumental triangular pedimented facades (TÜBA-AR, 2021; Karabağ, 2022; Amasya Municipality (n.d.)).
Materials and Construction Techniques	Cut stone, rubble stone, wood, brick; the walls were built with the overlapping method. Ancient cisterns were created with rock carving techniques (TÜBA-AR, 2021; Karabağ, 2022; Amasya Municipality (n.d.)).
Changes Over Time	The fortress was strengthened with repairs from 69 BC onwards; internal structures were added during the Ottoman period and abandoned after 1832. Since 2009, it has been revived with excavations (Canıbek, 2020; Karabağ, 2022; Amasya Municipality (n.d.)).
Conservation Status and Challenges	Most of the walls have been destroyed and only the foundations remain. However, it has gained archaeological and cultural importance thanks to excavations and conservation efforts after 2007 (Karabağ, 2022; TÜBA-AR, 2021; Amasya Municipality (n.d.)).
Current Usage	It is considered as an excavation site and cultural route. Kızlar Sarayı Mevkii has the potential to become an archaeological park (Karabağ, 2022; TÜBA-AR, 2021; Amasya Municipality (n.d.)).
Potential for Reuse	It can be re-functionalized as an open-air museum, cultural walkways and an area integrated with the integrity of the historical/cultural landscape (Canıbek, 2020; Karabağ, 2022; Amasya Municipality (n.d.)).
Place in the Urban Fabric and Integration Status	Kale is the oldest and central settlement of Amasya. During the Pontic period, a three-unit city structure was formed and the settlement spread to the plain over time. Today, the visual and physical relationship with the historical texture continues. (Karabağ, 2022; TÜBA-AR, 2021; Amasya Municipality (n.d.)).
Evaluation and Recommendations	Sustainable preservation of the multi-layered historical texture; supporting excavations; integrating the castle and its surroundings into cultural tourism are recommended. Public participation and local government cooperation are important (Karabağ, 2022; Canıbek, 2020; TÜBA-AR, 2021).

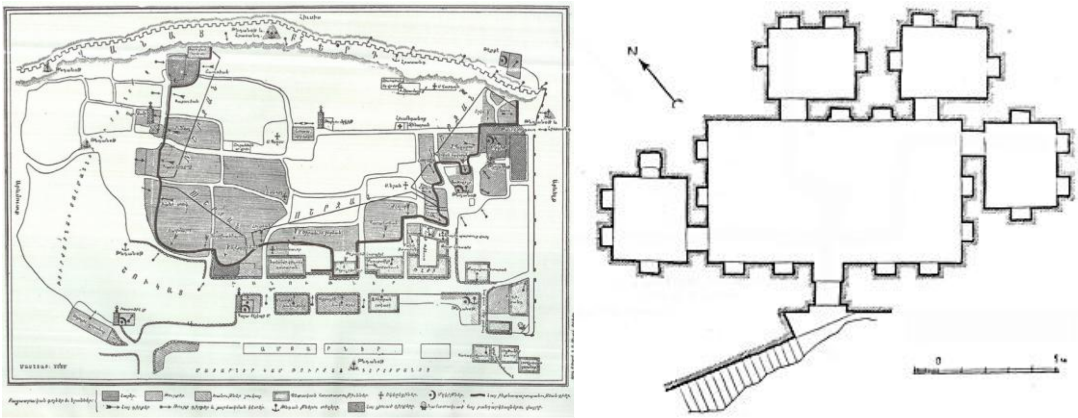

Fig. 3. Van Castle Plan (Konyar, E., Genç B. Avcı, C. & Tan, A., 2019, URL-8).

Table 4. Van Castle Analysis Table

Name of Structure	Van Castle
Location	Van province is located on a high cliff to the east of Lake Van (Tarhan & Sevin; Öztürk).
Construction Date / Period	It was built during the Urartian Kingdom (9th century BC) (Tarhan & Sevin; Ciloşoğlu & Açık; Erzen).
Producer / Produced by	It is associated with the construction process initiated by the Urartian King Sarduri I (Tarhan & Sevin; Genç & Konyar).
History of the Building	The fortress was used during the Urartian, Medieval, Seljuk and Ottoman periods and assumed military and administrative functions (Erzen; Ciloşoğlu & Açık; Tarhan & Sevin).
Architectural Features	The walls, built with massive cut stones, include a citadel, the Analıkız monument, bastions and towers from the Ottoman period (Genç & Konyar; Erzen; Tarhan & Sevin).
Materials and Construction Techniques	Horasan mortar, large cut stone, stone-filled walls; cyclopean walls and bedrock carving techniques were used (Tarhan & Sevin; Erzen; Öztürk).
Changes Over Time	From the 16th century onwards, defense systems were strengthened by the Ottomans; they became dysfunctional after the Republic (Ciloşoğlu & Açık; Erzen; Öztürk).
Conservation Status and Challenges	It was damaged in various periods; excavation and restoration works started after 1995 (Öztürk; Erzen).
Current Usage	It is considered as a cultural heritage site, archaeological excavation site and tourism destination (Öztürk; Tarhan & Sevin).
Potential for Reuse	It can be functionalized with the integration of open-air museum, cultural routes, memory space and landscape (Genç & Konyar; Öztürk).
Place in the Urban Fabric and Integration Status	It is associated with the Old Van City and is one of the focal points of urban memory and diffusion (Ciloşoğlu & Açık; Öztürk).
Evaluation and Recommendations	Preservation of its multi-layered structure, support for excavations and sustainable conservation with public participation are recommended (Erzen; Genç & Konyar; Öztürk).

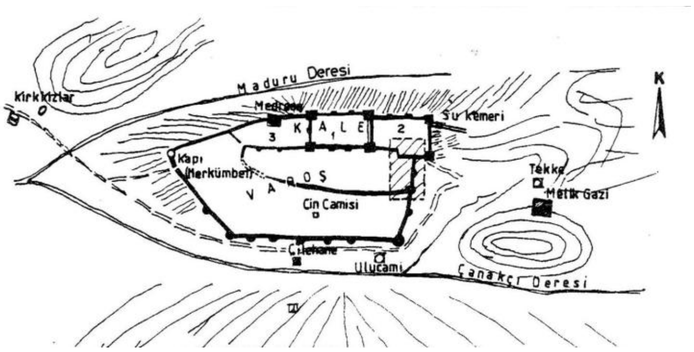

Fig. 3. Plan of Tokat Castle (URL-11).

Table 5. Tokat Castle Analysis Table

Name of Structure	Tokat Castle
Location	The province of Tokat is located on a steep hill that is an extension of the Akdağs, northwest of the city (Mesut Çıtak; 5th Tokat Symposium).
Construction Date / Period	The exact date of construction of Tokat Castle is unknown. The rock graves and the stepped water tunnel in the castle indicate a history dating back to the Pontic Kingdom period (1st century BC) (Mesut Çıtak). Some researchers suggest that the structure mayduring the Roman Empire (30 BC - 395 AD) (Kadir Çakar). The present fortress form is thought to have been strengthened during the Byzantine period, especially between the 4th-6th centuries AD.
Producer / Produced by	According to Evliya Çelebi, a person named Dok-ad from the Amelika tribe; according to other sources, it is related to the Byzantine Empress Eudoxia (5th Tokat Symposium).
History of the Building	It was used in Roman, Byzantine, Dânişmendli, Seljuk, Eretna, Kadı Burhâneddin and Ottoman periods; and assumed military, administrative and religious functions (Mesut Çıtak; Kadir Çakar; 5th Tokat Symposium).
Architectural Features	It contains walls, bastions, moats, worship areas, water cisterns, 362-step stone stairs and various structures in the inner castle (Kadir Çakar; 5th Tokat Symposium).
Materials and Construction Techniques	Cut stone, rubble stone, rock carving techniques were used; it was built in accordance with the topography (5th Tokat Symposium).
Changes Over Time	Its defense systems were strengthened during the Ottoman period; it lost its military importance in the 18th century (5th Tokat Symposium; Kadir Çakar).
Conservation Status and Challenges	It was destroyed over time; some structures were unearthed by archaeological excavations in recent years (Kadir Çakar).
Current Usage	It is considered as a cultural heritage site and tourism destination. Especially the dungeon section stands out (Kadir Çakar).
Potential for Reuse	Prison and sadness tourism can be evaluated within the scope of open-air museums and thematic cultural routes (Kadir Çakar).
Place in the Urban Fabric and Integration Status	It has enabled Tokat to become a classical fortress city; it has historical-urban integrity with the surrounding neighborhoods (Mesut Çıtak; 5th Tokat Symposium).
Evaluation and Recommendations	Preservation of the multi-layered structure, evaluation of the thematic tourism potential and sustainable conservation with public participation are recommended (Kadir Çakar; Mesut Çıtak; 5th Tokat Symposium).

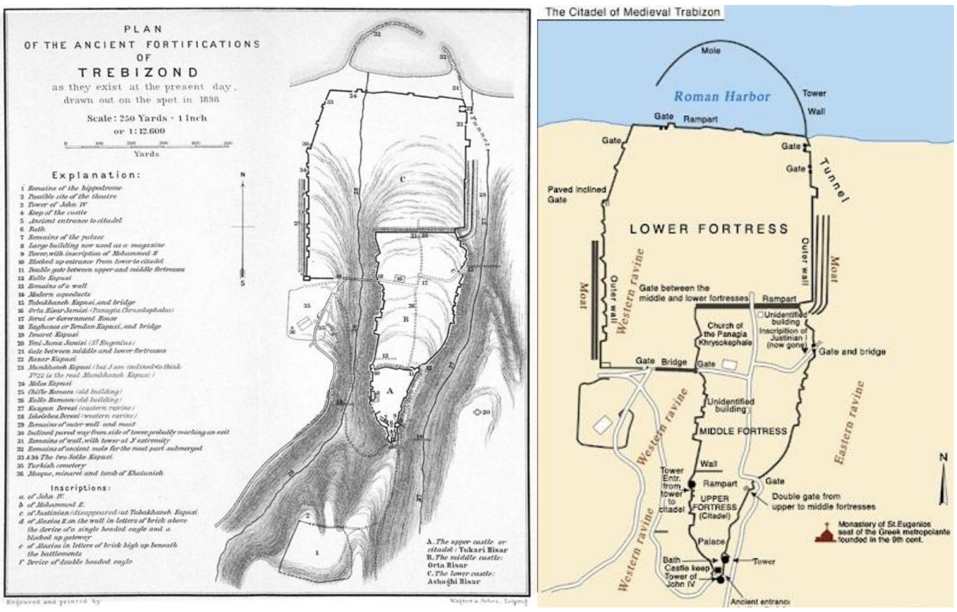

Fig. 4. Plan of Trabzon Castle (URL-13, 14).

Table 6. Trabzon Castle Analysis Table

Name of Structure	Trabzon Castle
Location	Trabzon is located between two valleys on a rocky outcrop suitable for the topography extending to the Black Sea coast. The city consists of parts: Upper Hisar (Inner Castle), Ortahisar and Lower Hisar (Fulya Üstün Demirkaya; Oğuz Kırcı).
Construction Date / Period	The first settlement dates back to the 7th century BC, the early phases of the city wall system date back to the Hellenistic period, and parts of the city walls date back to before the 3rd century AD (Trabzon History Volume ; Trabzon'da Fetih ve Şehir; Bilge Bahar).
Producer / Produced by	Although it is not certain by whom the first defense structures were built, important fortifications and a palace complex were constructed during the reign of the Komnenos of Trabzon (1204-1461) (Bilge Bahar; Trabzon'da Conquest and the City).
History of the Building	Trabzon Castle was used during the Roman, Byzantine, Komnenos, Ottoman and Republican periods and assumed military, administrative, religious and commercial functions (Bilge Bahar; Trabzon History Volume 2).
Architectural Features	The triple fortification system consisting of Upper, Middle and Lower Hisar includes towers, gates, palace buildings, baths, aqueducts, mosques and commercial buildings. The thickness of the walls exceeds 9 meters in some areas (Fulya Üstün Demirkaya; Trabzon'da Fetih ve Şehir; Bilge Bahar).
Materials and Construction Techniques	Cut stone and rubble stone were used; wall systems were built in harmony with the topography, parallel to the valleys and according to the slope (Bilge Bahar)
Changes Over Time	During the Ottoman period, the walls were fortified and new gates and bastions were added. In the 20th century, destruction occurred around the castle due to uncontrolled urbanization and transportation projects (Trabzon History Volume 2).
Conservation Status and Challenges	Although there are more than 500 registered buildings today, the integrity of the castle has been disrupted by modern construction; some parts of the city walls have become detached from today's urban fabric.
Current Usage	It is protected as a cultural heritage site and some parts are considered as tourism destinations. The palace ruins and aqueducts in the stand out (Bilge Bahar; Conquest and the City in Trabzon).
Potential for Reuse	Open-air museum, history-tourism routes, cultural activity areas for the castle and its surroundings can be planned (Conquest and the City in Trabzon).
Place in the Urban Fabric and Integration Status	It shaped Trabzon's 'kalekent' identity. The fortification systems determined the urban morphology and settlement plans (Fulya Üstün Demirkaya).
Evaluation and Recommendations	Conservation of the multi-layered historical texture, the creation of site management plans, increasing local participation and sustainable conservation strategies compatible with cultural tourism are recommended (Bilge Bahar; Conquest and the City in Trabzon).

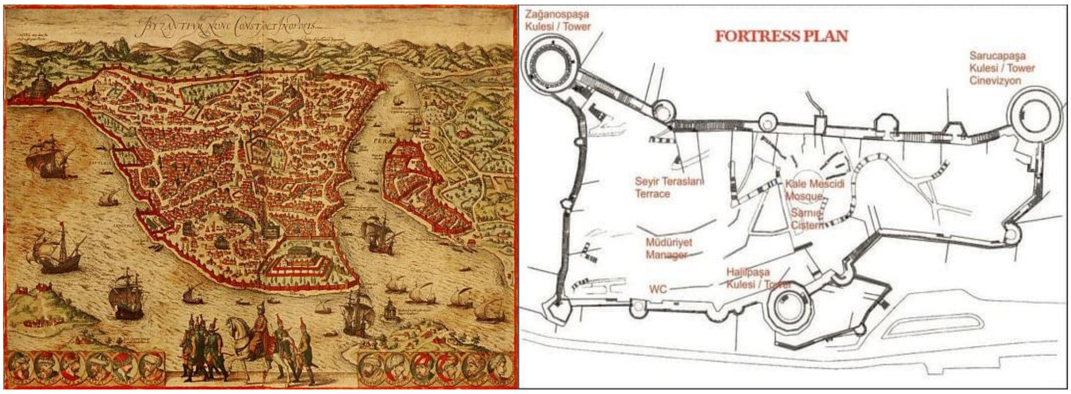

Fig. 5. Istanbul Old Map and Rumeli Hisarı Plan (URL-18, URL-19).

Table 7. Istanbul Rumeli Hisarı Analysis Table

Name of Structure	Istanbul Rumeli Hisarı
Location	The province of Istanbul is located on the European side of the Bosphorus, between Baltalimanı and Bebek, on the narrowest point of the Bosphorus. (Engin Özerler; Hülya Utkuluer)
Construction Date / Period	Built in 1452 by Mehmed II before the conquest of Istanbul (Abdullah Mehmet Avunduk; Engin Özerler)
Producer / Produced by	It was built by the Ottoman Sultan Mehmed II. (Aynur Can; Hülya Utkuluer)
History of the Building	It was built in 1452 for defense purposes, used as a prison after the conquest, and gained a historical identity over time. (Abdullah Mehmet Avunduk; Hülya Utkuluer)
Architectural Features	It consists of three large towers, thirteen small bastions and fortification walls in a plan close to rectangular. The towers are named with the letters A-B-C. (Abdullah Mehmet Avunduk)
Materials and Construction Techniques	Rubble stone, limited brick, spolia; spolia stone is used close to the coast. (Abdullah Mehmet Avunduk)
Changes Over Time	It has undergone earthquakes, fires, restorations; a comprehensive restoration in 1953 and a process that was restarted in 2021. (Hülya Utkuluer; Abdullah Mehmet Avunduk)
Conservation Status and Challenges	Additions such as the construction of a theater were criticized, and a new restoration process was initiated by IBB in 2021. (Hülya Utkuluer)
Current Usage	It is used as a cultural event space; its function as a museum and stage has diminished over time. (Aynur Can; Hülya Utkuluer)
Potential for Reuse	Open-air museum, revitalization of historical and cultural activities, strengthening ties with the local community. (Aynur Can; Hülya Utkuluer)
Place in the Urban Fabric and Integration Status	Part of the Bosphorus silhouette, it is in a neighborhood structure where different socioeconomic groups are intertwined. (Aynur Can)
Evaluation and Recommendations	In addition to physical restoration, social memory, local identity and cultural continuity need to be preserved. (Aynur Can; Hülya Utkuluer)

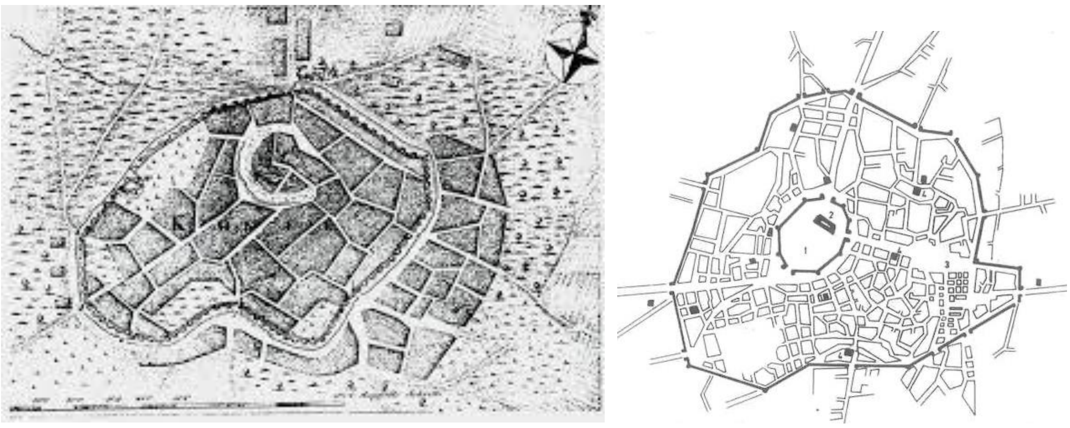

Fig. 6. Plan of Konya Castle (URL-23).

Table 8. Konya Castle Analysis Table

Name of Structure	Konya Castle
Location	Inner Castle: Alaeddin Hill; Gevale: Takkeli Dağ, 1675 m altitude; Ahmedek: West of Alaeddin Hill; Outer Castle: Surrounding Konya (Ahmet Şen; Emine Güney; Konya'nın Savunma Yapıları-Cilt 22 Issue 3)
Construction Date / Period	It was founded during the Roman period, strengthened during the Byzantine period, and major fortifications were built during the Seljuk period during the reigns of Kılıçarslan II (1156-1192) and Alaeddin Keykubat I (1220-1237). (Mustafa Önge; Konya'nın Savunma Yapıları-Cilt 22 Issue 3)
Producer / Produced by	Kılıçarslan II, Alaeddin Keykubat I, İzzeddin Keykâvus I (Emine Güney; Yusuf Küçükdağ et al.; Konya'nın Savunma Yapıları-Cilt 22 Issue 3)

Table 8. continued

History of the Building	Konya Castle is a multi-layered defense structure dating from Roman to Ottoman times. Gevale Castle was used as a diplomatic center and palace; Ahmedek as a dungeon; and the Outer Castle as a structure associated with urban expansion. (Ahmet Şen; Emine Güney; Konya'nın Savunma Yapıları-Cilt 22 Issue 3)
Architectural Features	Multi-layered defense system: İç Kale, Gevale and Ahmedek castles; fortifications with towers; moated layout; rectangular bastions (Mustafa Önge; Yusuf Küçükdağ et al.)
Materials and Construction Techniques	Cut stone, rubble stone, Sille stone; the walls were supported by rectangular bastions (Ahmet Şen; Mustafa Önge)
Changes Over Time	With the Tanzimat, the city walls were dismantled; Ahmedek became a quarry; Gevale lost its military importance (Mustafa Önge; Konya'nın Savunma Yapıları-Cilt 22 Issue 3)
Conservation Status and Challenges	Only the foundations of Ahmedek remain; Gevale is known with limited physical remains; and most of the Castle is known with traces of(Emine Güney; Konya'nın Savunma Yapıları-Cilt 22 Issue 3)
Current Usage	Ahmedek parking lot/art gallery; Gevale is considered an archaeological site (Emine Güney; Mustafa Önge)
Potential for Reuse	Archaeological park can be re-functionalized as a cultural route focused on urban memory (Ahmet Şen; Emine Güney)
Place in the Urban Fabric and Integration Status	Alaeddin Hill surrounds the city center; Gevale overlooks the city from a height; city wall gates influenced the spatial orientation (Konya's Defense Structures - Volume 22 Issue 3; Emine Güney)
Evaluation and Recommendations	Social memory should be preserved along with physical traces; public awareness should be supported (Ahmet Şen; Mustafa Önge; Konya'nın Savunma Yapıları-Cilt 22 Issue 3)

Table 9. Sivas Castle Analysis Table

Name of Structure	Sivas Castle
Location	It is located on a natural elevation called Topraktepe in the center of Sivas province. (Levent Keskin; Oğuz Ceylan)
Construction Date / Period	The first traces of settlement date back to the 2nd millennium BC; it was fortified during the Byzantine period and rebuilt during the Seljuk period. (Oğuz Ceylan; Levent Keskin)
Producer / Produced by	It was fortified during the reign of Byzantine Emperor Justinian and rebuilt during the reigns of Dânişmend Gazi and Anatolian Seljuk Sultan Alaeddin Keykubâd I. (Oğuz Ceylan)
History of the Building	It is a multi-layered structure witnessing the Hittite, Roman, Byzantine, Seljuk and Ottoman periods. (Levent Keskin; Hülya Kaya Hasdemir)
Architectural Features	It consists of and castle; built on a sloping terrain; and houses water cisterns, bastions, weapon depots, a mosque and a church. (Abdullah Kaya; Oğuz Ceylan)
Materials and Construction Techniques	Large cut stone, rubble stone and spolia were used. The walls reach 15-20 meters (Oğuz Ceylan)
Changes Over Time	Destroyed by Timur's attack, it was restored during the Ottoman period. After 2015, restorations were carried out. (Oğuz Ceylan; Abdullah Kaya)
Conservation Status and Challenges	Cracks, stone removal and deformations were observed on the wall surfaces. (Abdullah Kaya)
Current Usage	It is protected as part of the historic skyline, but has been largely abandoned. (Abdullah Kaya)
Potential for Reuse	It can be integrated with archaeological parks, open air museums and cultural routes. (Erdal Eser; Hülya Kaya Hasdemir)
Place in the Urban Fabric and Integration Status	Topraktepe is a strategic focal point in urban memory; it is integrated with the public spaces around it. (Levent Keskin; Hülya Kaya Hasdemir)
Evaluation and Recommendations	Revitalization of social memory, preservation of historical continuity and scientific restoration are necessary. (Hülya Kaya Hasdemir; Erdal Eser)

Fig. 7. Antalya Castle - 1957 Beyru et al. Plan (Özer, 2023).

Table 10. Antalya Castle Analysis Table

Name of Structure	Antalya Castle
Location	It is located in the Kaleiçi district of Muratpaşa district in Antalya province. It is in the old city center surrounded by walls overlooking the Mediterranean Sea. (Fatih Yilmaz)
Construction Date / Period	Founded by Attalos II in the 2nd century BC, the city was fortified with walls during the Roman period; its layered defense structure developed during the Middle Ages, and it came under Seljuk rule in 1207 and Ottoman rule in 1423. (1905-Evren Dayar)
Producer / Produced by	Roman Emperor Hadrian (Hadrian's Gate), Seljuk Sultan Alaeddin Keykubad I (Fluted Minaret), Hassa Architect Mustafa Raşid Efendi (1815 restoration). (Fatih Yılmaz; Evren Dayar)
History of the Building	Although the foundations of the urban fabric date back to the settlement of Korykos, the fortification systems were shaped by the Romans and fortified during the Byzantine and Seljuk periods. The 1905 maps show three districts bounded by the inner fortress and the outer walls. (1905-Evren Dayar)
Architectural Features	The triple fortification system (moat, curtain wall, outer wall) was supported by monumental structures such as Hıdırlık Tower, Hadrian's Gate and Fluted Minaret. (Evren Dayar; Özgen Kurt)
Materials and Construction Techniques	In addition to materials such as cut stone, spolia stone and memzûc mortar, traces of these techniques can be traced in structures such as the Baruthane Burcu and the palace baths on the 1905 maps. (1905-Evren Dayar)
Changes Over Time	After the 1895 fire, the neighborhood fabric was destroyed, and 1905 maps document fire areas, empty parcels and structural changes. (1905-Evren Dayar)
Conservation Status and Challenges	After 1905, with the modernization process, many city gates were removed and the expansion of the city led to the wall system being limited to a symbolic function. (1905-Evren Dayar)
Current Usage	Tourism, marina, cultural heritage area; some areas are used as archaeological parks and museums (Fatih Yılmaz; Özgen Kurt)
Potential for Reuse	Cultural routes, archaeological parks and open air museums can be integrated with tourism and education. (Evren Dayar; Özgen Kurt)
Place in the Urban Fabric and Integration Status	Kaleiçi is divided into three zones; these areas, bounded by the inner city walls, have assumed a central role in urban memory with the harbor and religious buildings. (1905- Evren Dayar)
Evaluation and Recommendations	Scientific restoration, interdisciplinary planning and strengthening social memory are recommended for the preservation of the historical fabric. (Evren Dayar; Özgen Kurt; Fatih Yılmaz)

4. Conclusions

Within the scope of the study, comparative analyses of 10 different castle-city examples in Anatolia have revealed findings on the conservation, re-functionalization and integration of historical walls and castles into the modern urban fabric. The analyzed examples show that similar problems were encountered periods and at urban scales, but the conservation and integration strategies applied varied. Partial conservation and reuse practices were observed in Kayseri, Erzurum and Trabzon; whereas in cities such as Konya, Sivas and Tokat, the remains of the city walls were largely destroyed and integration remained weak. In the case of Rumeli Hisarı, it was observed that the military history of the structure could be integrated with the cultural tourism potential, while archaeological excavations and cultural routes contributed to the conservation processes in the castles and walls of Van and Amasya. In the examinations and evaluations;

- Most of the historical walls and castles in Anatolia lost their military functions over time and remained under the pressure of urbanization
- In many castles, restoration practices are carried out for touristic and economic purposes rather than preserving the original values;
- Historic walls and fortresses continue to be the main elements that guide the morphological development of cities, but modern development practices have seriously damaged this integrity;
- Project-oriented approaches override holistic conservation objectives;
- When the level of public participation and social awareness is low, the integration of historic buildings into daily life is limited;

results have been reached. In this framework, it is necessary to prioritize the original identity in the protection of the original architectural, cultural and social values of historical buildings in restoration and re-functioning works; modern interventions should not harm this identity; sustainable integration models should be planned, in this context, walls and castles should be planned not only as touristic destinations but also as public spaces that are actively used in the daily life of local people; participatory conservation processes should be increased by ensuring effective cooperation between local administrations, academia and non-governmental organizations; comprehensive site management plans should be prepared especially for large-scale and multi-layered historical sites, and in this context, a balance between conservation, use and promotion should be established; innovative functionalization strategies should be determined and cultural routes, open-air museums, culture - art activity areas and sustainable tourism projects and re-functioning projects should be developed for historical walls and castles under the supervision of expert architects; the current status of the buildings should be documented in digital environment and regular follow-up of the conservation processes should be ensured. It should be kept in mind that historical fortifications and castles are not only structures bearing the traces of the past, but also living assets that shape the cultural identity, social memory and spatial continuity of cities, and therefore conservation and integration processes should not be limited to short-term projects; they should be carried out on the basis of sustainable, holistic and participatory approaches.

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Preserving Algeria's architectural heritage: Balancing tradition and modern restoration practices

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Abstract. Algeria's rich architectural heritage faces significant challenges in preservation and restoration, particularly in the context of aging buildings and the rapid urbanization of the country. This study examines the conservation and restoration practices of historical structures in Algeria, with a focus on preserving cultural identity while addressing modern needs. The methodology combines fieldwork involving the assessment of key historical sites, such as Ottoman and French colonial buildings, with expert interviews and archival research. The research investigates the current approaches to conservation, comparing traditional techniques with modern restoration methods that integrate advanced materials and technologies. Results show that the most successful restoration projects are those that carefully balance the original construction materials—such as stone, clay, and wood—with modern, sustainable solutions, including the use of bio-based materials and energy-efficient systems. Challenges in conservation include the lack of standardized guidelines, insufficient funding, and the risk of losing authenticity due to overzealous modernization. However, pilot projects focused on adaptive reuse, such as transforming old palaces into cultural centers, demonstrate that careful restoration can breathe new life into heritage buildings while respecting their historical value. The study concludes by proposing a comprehensive framework for improving conservation practices, emphasizing the importance of collaboration between government bodies, local communities, and conservation experts. The aim is to promote a holistic approach that combines technical expertise with cultural sensitivity to safeguard Algeria's architectural heritage for future generations.

Keywords: Conservation; Restoration; Architectural heritage; Algeria; Adaptive reuse

1. Introduction

Algeria possesses a rich and multifaceted architectural heritage that reflects centuries of historical, cultural, and geopolitical transformations. From the majestic Roman ruins of Timgad and Djemila to the intricate Islamic architecture of the Almoravid and Ottoman dynasties, and the symmetrical facades of French colonial urbanism, Algeria's built environment serves as a living archive of Mediterranean and North African civilizations (Bouchène et al., 2012). These architectural forms are not only valued for their aesthetic and historical significance but also for the intangible cultural narratives they carry—stories of identity, adaptation, and resilience (UNESCO, 2019).

However, this invaluable heritage is under increasing threat. The pressures of rapid urbanization, especially in major cities like Algiers, Oran, and Constantine, have led to the encroachment upon or even the demolition of historic quarters to make way for modern developments (Djabri & Bouchlaghem, 2021). Environmental degradation, including rising humidity, air pollution, and the effects of climate change, accelerates the deterioration of ancient building materials such as limestone, adobe, and wood (González-Zambrano et al., 2020). Moreover, insufficient conservation policies, lack of public awareness, and a shortage of skilled artisans trained in traditional techniques have exacerbated the deterioration of heritage sites (Fakhar, 2016).

While governmental and international efforts—such as the UNESCO designation of the Kasbah of Algiers—have raised awareness, many restoration projects remain inconsistent and sometimes misguided. Interventions often prioritize aesthetics over structural or historical fidelity, occasionally resulting in irreversible damage or loss of authenticity (Benamara, 2018).

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This study investigates the potential of combining traditional knowledge systems—like lime plastering, rammed earth, and wood joinery—with modern restoration tools, such as digital surveying, non-destructive testing (NDT), and sustainable building materials. The goal is to propose a culturally sensitive and technically viable approach to conserving Algeria's architectural heritage that ensures its endurance and relevance for future generations (Lourenço et al., 2019).

By analyzing field-based case studies and recent restoration experiences, the objectives of this article are to:

Evaluate the current state of heritage conservation practices in Algeria;

Examine the comparative effectiveness of traditional and modern techniques;

Identify key challenges and best practices;

Propose a hybrid restoration framework adapted to Algerian contexts.

Ultimately, this research underscores the need for an interdisciplinary and balanced approach that values historical authenticity, local knowledge, technological innovation, and environmental sustainability (Avrami et al., 2000). Preserving Algeria's architectural legacy is not merely about maintaining old buildings, but about safeguarding the collective memory and identity embedded within them.

2. Methodology

This study employs a qualitative and exploratory approach, combining field research, expert insights, and historical documentation to evaluate heritage conservation strategies in Algeria. The goal is to identify successful restoration practices that integrate traditional techniques with modern materials and technologies.

2.1. Site Selection and Contextual Analysis

Representative heritage sites were selected from key urban regions in Algeria, including Ottoman palaces in Constantine, Kasbah structures in Algiers, and French colonial facades in Oran. The selection criteria included architectural diversity, current conservation status, historical relevance, and accessibility.

2.2. Field Survey and Documentation

A comprehensive field survey was conducted at each site. This involved:

On-site observations to assess the condition of materials, structural integrity, and previous interventions.

Photographic documentation of façades, materials, details, and pathological manifestations (cracks, humidity, erosion).

Architectural assessment using sketches and measurements to analyze traditional construction systems such as stone masonry, rammed earth walls, and timber framing.

2.3. Expert Interviews

Semi-structured interviews were held with architects, heritage conservators, engineers, and local craftsmen. These interviews aimed to:

Understand the challenges faced in conservation efforts.

Document knowledge of traditional building techniques.

Evaluate the perception of modern restoration interventions.

2.4. Archival Research

Historical maps, colonial records, technical restoration reports, and UNESCO documentation were analyzed to reconstruct the architectural history of each site and understand previous preservation efforts.

2.5. Data Analysis and Synthesis

The collected data were thematically analyzed to compare:

Traditional restoration techniques (lime plaster, stone joints, earth reinforcement)

Modern restoration techniques (fiber-reinforced materials, chemical consolidants, digital scanning)

A comparative matrix was created to assess the efficiency, authenticity preservation, and sustainability of each approach.

2.6. Framework Development

Based on the results, a hybrid conservation framework was proposed. It balances technical rigor with cultural sensitivity, aiming to guide future restoration policies and on-site practices.

3. Results and Discussion

3.1. Comparative Performance of Restoration Techniques

Through extensive site documentation and expert analysis, three dominant approaches emerged in the Algerian context:

Traditional methods: such as lime plastering, wooden joinery, and stone masonry.
Modern methods: including epoxy resins, synthetic sealants, and concrete-based repairs.
Hybrid approaches: combining traditional craftsmanship with modern technologies.
The Fig. 1 provides a comparative analysis based on four criteria:
Authenticity retention: Traditional methods scored the highest (90%), while modern approaches often compromise historical integrity.
Material sustainability: Hybrid solutions outperformed others by integrating eco-friendly materials (e.g., bio-based binders).
Cost-efficiency: Hybrid solutions remain economically viable, especially in adaptive reuse projects.
Durability: Modern and hybrid solutions demonstrated superior longevity.

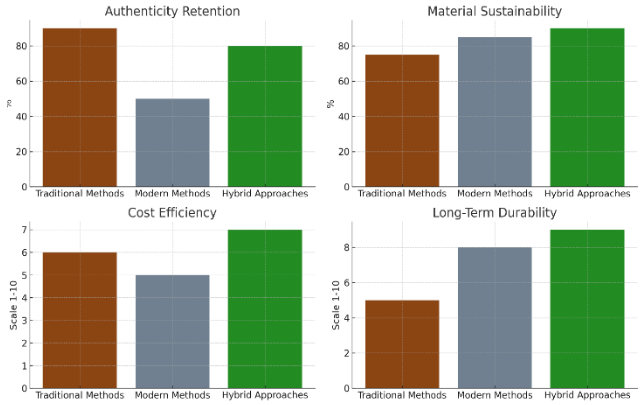

Fig. 1. Comparative performance of restoration methods in terms of authenticity, sustainability, cost, and durability

3.2. Case Studies of Successful Interventions
a) The Palace of Ahmed Bey (Constantine)
This Ottoman-era structure was restored using lime-based mortars, hand-carved cedar wood, and digital scanning for accurate measurements. The project succeeded in preserving intricate details while improving structural integrity (Fig.2).

Fig. 2. Interior view of restored wooden ceiling at Ahmed Bey Palace, Constantine

b) Casbah of Algiers
In the heart of Algiers, restoration projects were guided by UNESCO protocols. Some dwellings were rehabilitated using hybrid methods, maintaining mud-brick walls while reinforcing foundations with carbon fiber mesh (Fig.3).

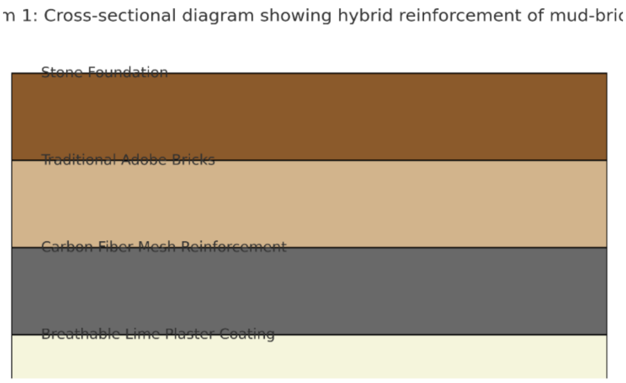

Fig. 3. Cross-sectional diagram showing hybrid reinforcement of mud-brick wall

c) Colonial Villas in Oran

These buildings faced damage due to concrete degradation and moisture. Restoration integrated breathable waterproof plasters and green roof systems to prevent water ingress and promote energy efficiency (Fig. 4).

Fig. 4. Restored facade of a colonial villa in Oran using eco-compatible materials

3.3. Obstacles and Constraints

Several systemic and technical obstacles were identified:

Lack of standardized guidelines: Practitioners often lack consistent manuals, leading to varied results.

Funding gaps: Many projects rely on international aid or temporary municipal budgets, compromising continuity.

Over-modernization: Overuse of incompatible materials (e.g., cement, PVC) alters the buildings' thermal and aesthetic qualities.

Loss of traditional skills: Many local artisans no longer practice heritage construction methods, risking permanent knowledge loss.

Table 1. Summary of challenges encountered in heritage restoration projects.

Challenge	Impact	Example
Non-compatible materials	Structural cracking, humidity issues	Kasbah cement repairs
Funding inconsistency	Project discontinuation	Oran municipal restorations
Lack of skilled artisans	Loss of craftsmanship and authenticity	Elimination of zellij patterns
Regulatory gaps	Conflicts between ministries and cities	Constantine project delays

3.4. Benefits of Adaptive Reuse

Projects that transformed heritage structures into museums, community centers, or guesthouses showed multiple benefits:

Extended building lifespan

Tourism and socio-economic gains

Stronger community engagement (Fig. 5)

Fig. 5. Former Ottoman residence converted into a cultural center in Tlemcen

4. Conclusion

The preservation of Algeria's architectural heritage stands at a critical crossroads, shaped by the tension between respecting traditional craftsmanship and embracing modern innovation. This study has shown that a hybrid approach—where modern techniques and sustainable materials are integrated with traditional restoration methods—offers the most promising path forward. Such an approach not only ensures structural durability and energy efficiency but also retains the authenticity and cultural integrity of heritage buildings.

Through comparative analysis of restoration techniques and field evaluations, the research highlights that projects which value historical context, engage local expertise, and adopt environmentally conscious strategies are more successful and socially accepted. The inclusion of community stakeholders, conservation experts, and interdisciplinary teams emerges as a fundamental pillar for effective heritage management.

However, the challenges remain significant. The absence of standardized conservation guidelines, limited funding, and the growing pressure of urban development pose ongoing threats to Algeria's historical sites. If left unaddressed, these factors could accelerate the erosion of cultural identity embodied in the built environment.

Therefore, this article advocates for a national conservation framework grounded in adaptive reuse, education, and policy reform. By encouraging local authorities, academic institutions, and civil society to collaborate in documenting, restoring, and reusing historic structures, Algeria can safeguard its architectural legacy for future generations. It is not merely about preserving old walls, but about protecting the narrative, memory, and soul of Algerian cities.

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Artificial intelligence (AI) assisted digital reconstruction of historical buildings

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Abstract. Historical buildings, as an essential component of cultural heritage, historical traces of the past to the present. However, they are confronted with the need for conservation and reconstruction due to the natural effects and human intervention they are exposed to over time. Artificial intelligence (AI) and digital tools provide significant contributions to the documentation and reconstruction processes of historical buildings. This study utilises digital modeling techniques to document historical structures that are critically endangered cultural heritage, while utilizing artificial intelligence-assisted methods to reconstruct destroyed or damaged sections of the building. The study aims to document damaged or partially destroyed historical buildings with digital tools and to produce AI-assisted reconstruction representations. In this context, historical buildings in Mardin that reflect the rich cultural heritage of Anatolia were discussed. The study consists of 6 stages: data collection, literature review, fieldwork, digital documentation process, AI-assisted image generation and evaluations. During the documentation process, high-accuracy 3D models of the current status of the buildings were produced, while the image generation process was conducted through an artificial intelligence using diffusion-based algorithms. This process offers an effective solution for faster prediction in the reconstruction of destroyed historical buildings. The study concluded that, with technological developments, both effective use of digital tools and AI-assisted research can contributes to the processes of preserving cultural heritage and passing on to future generations.

Keywords: Historical buildings; Artifical intelligence; AI; Digital reconstruction; Mardin

1. Introduction

Historical buildings are the most important physical landmarks that shape the collective memories of societies, build their identities, and maintain cultural continuity. Their architectural forms, use of materials, construction techniques, and spatial organisation make them more than just physical objects. Historic buildings also hold valuable information about the social, economic, political, cultural and historical characteristics of the geography in which they are constructed (Jokilehto, 2017; Feilden, 2007). In this context, these buildings are not only valuable evidence of the past but also sustainable elements of the cultural connections to be created with future generations (UNESCO, 2011). However, over time, this valuable heritage faces the risk of destruction or complete disappearance as a result of natural disasters, wars, environmental conditions, negligence and ineffective interventions (De la Torre, 2013; Avrami et al., 2019; Demas, 2002). This situation has led to an urgent need to conserve, document, and, where necessary, reconstruct historical buildings.

In the twenty-first century, more systematic, accessible and practical approaches to cultural heritage management have become possible through the integration of digital technologies with traditional conservation and restoration methods (Guidi et al., 2009; Remondino & Rizzi, 2010). Digital documentation techniques such as photogrammetry, laser scanning, heritage building information modelling (HBIM), geographic information systems (GIS), thermal imaging, and three-dimensional (3D) modelling allow for detailed analysis of the current condition of buildings while also providing supportive tools for monitoring deterioration processes and decision-making (Dore & Murphy, 2012). Using these technological tools, digital records can be generated with high accuracy, even in areas where physical access is difficult or dangerous. This enhances the sustainability of conservation and interventions (Letellier & Eppich, 2015; Spallone et al., 2017). Since the beginning of the twenty-first century, artificial intelligence (AI) has become another important element, transforming the field of cultural heritage. In particular, algorithms such as computer vision, object recognition, deep learning, and generative adversarial neural networks (GANs) can develop fast and data-driven solutions for the reconstruction of missing parts of damaged or completely destroyed structures (Wang & Xiong, 2022; Li, 2021; Zhu et al., 2025). AI-assisted systems have the potential to offer a new paradigm in reconstruction processes by supporting human expertise,

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especially in tasks such as interpolation of missing parts and recognition of similar structural patterns (Trzeciak & Brilakis, 2023; Oreni et al., 2013). These technologies not only provide fast and accuracy but also provide a scientific basis for simulating different scenarios of the reconstruction process (Mishra et al., 2024; Karimi et al., 2024).

Reconstruction is the practice of producing a representation of the building in its original state, particularly in cultural heritage buildings where the original materials and form were damaged. Today, digital reconstruction makes it possible not only to re-visualise physically lost parts but also to reconstruct these representations by verifying them with multiple data sources (photographs, drawings, archival documents, written witness accounts) (Fernández-Palacios et al., 2017; Kuroczyński et al., 2014). In this process, data generation tools supported by artificial intelligence can identify the patterns of damaged parts and generate possible reconstruction scenarios. When the literature on digital reconstruction is examined, Giovannini (2018) proposed the "Virtual Reconstruction Information Management Modelling (VRIMM)" methodology, emphasising that uncertainties and interpretations in 3D digital reconstruction processes should be documented transparently. Brumana et al. (2013), on the other hand, developed a HBIM-based approach for cultural heritage buildings, integrating scanning and survey data and demonstrating that conservation activities can be managed more effectively. Mary (2025) stated that generative AI technologies have a transformative potential in cultural heritage conservation. Marchello et al. (2023) discussed the innovative effects of Virtual Reality (VR) and Augmented Reality (AR) technologies on digital representations of cultural heritage through case studies of digital reconstruction in the context of knowledge production, narrative fiction and user participation. Arzomand et al. (2024) indicate that AI-assisted text-to-image generation processes integrate with historical data to develop a new and dynamically based approach to the reconstruction of heritage buildings. Fang et al. (2024) suggested a method that combines 3D point cloud data and diffusion-based AI techniques to create very accurate and stable digital models of historical buildings. Croce et al. (2023) proposed an AI-assisted semi-automated Scan-to-BIM approach to increase the automation of the conversion of historical buildings from point cloud data to digital reconstruction models. Chashyn et al. (2024) developed a systematic approach for the digital management of historical buildings by proposing a city intelligent modelling (CIM)-based analysis platform and supported HBIM processes with the integration of parametric modelling and advanced data analysis. These developments in the literature greatly enhance the technological dimensions of digital reconstruction processes.

Digital documentation and reconstruction of cultural heritage requires new applications that examine the possibilities offered by AI-assisted digital methods through local examples. This study focuses on the digital documentation and AI-assisted digital reconstruction of historical buildings in Mardin, an important cultural heritage site, using the possibilities offered by technology. The aim of this study is to preserve endangered cultural heritage structures through digital representations and to develop a comprehensive and reliable documentation model that enables their reconstruction using AI-assisted methods. During the six-stage research process, the data collected through field studies were converted into high-accuracy 3D digital models. In addition, using AI-assisted diffusion-based algorithms for the damaged parts of the buildings, the damaged parts were reconstructed using digital images. Digital reconstruction processes are considered in two different approaches: image completion and new image generation. From this perspective, the study fills an important gap in the literature in terms of demonstrating the potential of AI-assisted reconstruction processes and revealing the effectiveness of digital technologies in documenting cultural heritage.

2. Materials and Methods

Mardin, located in the Southeastern Anatolia Region of Turkey, has an important dataset in terms of cultural heritage, with its unique urban texture containing traces of different civilisations. Throughout history, Mardin has hosted many civilisations, such as Assyrian, Roman, Byzantine, Artuqid and Ottoman (Dursun, 2024; Aydın et al., 2024). Today, it presents a unique urban identity with its cultural heritage, which is characterised by traditional stonework, religious buildings, and government buildings reflecting the traces of these civilisations (Fig. 1). Within the scope of this study, two different scales of examples reflecting the cultural heritage characteristics of the city of Mardin were examined. Digital reconstruction applications were conducted on the civil architecture example in Midyat and the ruined fortification wall of the ancient city of Dara. In this study, involving a cross-scale analysis, traditional buildings and fortification walls were considered to evaluate the potential of digital reconstruction of damaged structures that differ in both function and scale.

Fig. 1. The heritage sites considered within the scope of the study

Advancing digital technologies significantly increases the potential for the use of new tools in conservation, restoration, and urgent intervention efforts at cultural heritage sites. In particular, it has become possible to integrate digital technologies effectively in the reconstruction of historical buildings and the development of intervention strategies, beyond documentation processes. This method provides higher accuracy, data-based analysis and multi-layered representation in conservation practices and improves the systematisation of intervention processes. In this study, a six-stage methodological approach was adopted for the digital documentation and AI-assisted reconstruction of cultural heritage buildings utilising these technologies (Fig. 2).

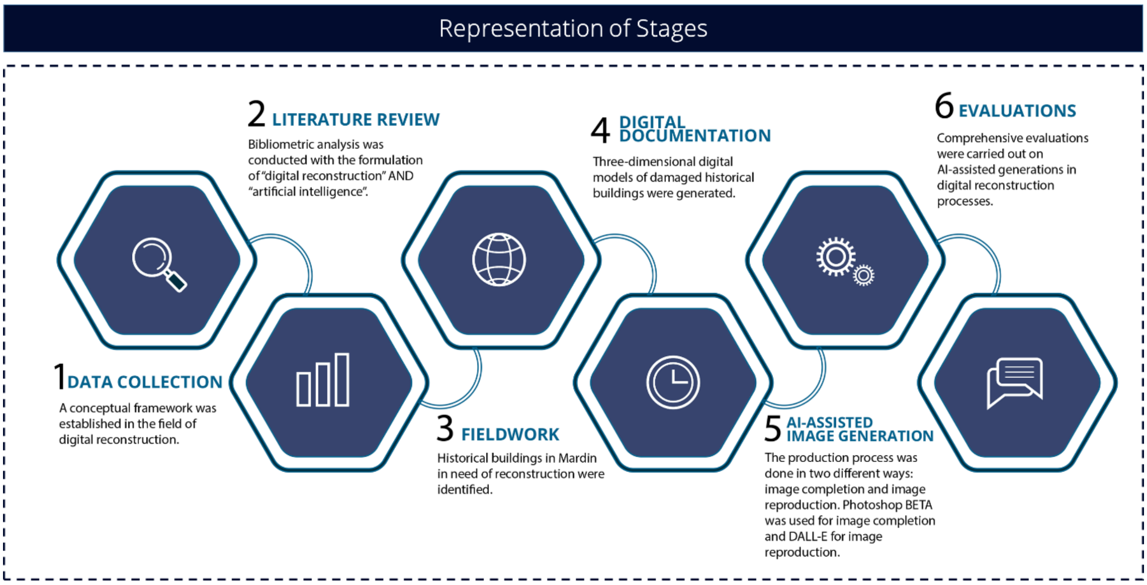


Fig. 2. Methodological flowchart of the study

The first stage of the study was the data collection process. At this stage, the conceptual framework of digital documentation techniques and reconstruction for cultural heritage buildings was defined. In the second stage, a literature review was conducted. Using the Web of Science (WoS) database, studies on digital reconstruction applications and AI-assisted methods for cultural heritage buildings were systematically analysed. Bibliometric analysis was performed through the VOSViewer software, and the main research trends and keyword correlations in the literature were visualised. Bibliometric analysis is considered an effective method for investigating knowledge production processes and identifying gaps in a particular field (Donthu et al., 2021). The third stage of the study involved fieldwork. Fieldwork was carried out in Mardin's historical heritage sites to document heavily damaged or demolished buildings on site and to record their current condition in detail. Field studies are considered an essential research method in documentation and intervention processes as they enable direct observation of the physical and spatial characteristics of cultural heritage buildings (Dimes & Ashurst, 2007). In the fourth stage, digital models of the buildings selected during the fieldwork were generated. Three-dimensional digital modelling has become a fundamental tool in cultural heritage studies in terms of documenting the current situation and providing basic data for reconstruction processes (Guidi et al., 2009). In the fifth stage, AI-assisted digital reconstruction processes were performed. This stage employed two distinct AI tools. The AI-assisted completion module of Photoshop Beta was used to complete the existing images, and the DALL-E 3 inpainting model was used to produce new images. Diffusion-based visual production technologies are gradually becoming widespread in the field of cultural heritage for the completion of incomplete data sets and the development of reconstruction alternatives (Gîrbacia, 2024; Bevilacqua et al., 2022). In the final stage, the resulting digital models and AI-assisted reconstruction outputs were comprehensively evaluated.

3. Findings

The findings section of the study presents both the current research trends in the literature and the original data obtained from field studies within the framework of a multi-layered analysis. In this context, the role of AI-assisted digital reconstruction applications in the field of cultural heritage was determined through bibliometric methods. Then, the digital models and AI-assisted reconstruction representations produced as a result of the field studies conducted in the city of Mardin were analysed. Thus, with the findings obtained, a holistic relationship was created between both the theoretical framework and the applied outputs, and the contributions of the research to the literature and field studies were revealed from different perspectives.

3.1. Bibliometric Analysis of AI-Assisted Digital Reconstruction Studies

The increasing trend towards AI-assisted digital reconstruction studies in the field of cultural heritage indicates that technology has become not only a documentary tool but also an active actor in the reproduction, completion and interpretation of cultural data. A bibliometric search of the WoS database with the formulation *"digital reconstruction" AND "artificial intelligence"* revealed that the first study in this field was conducted in 2016. The search was carried out under the heading "Topic", and all academic studies obtained as a result of the search were considered without any classification. As a result of the search, it was determined that there were a total of 10 studies as of April 2025. These studies were systematically examined, and the themes, basic field trends and methodological diversity of AI-assisted digital reconstruction studies were determined. The studies were presented in table form in chronological order as *"Authors, Publication Year, Title, Research Area, Country, Document Type"* (Table 1).

Table 1. Overview of selected studies indexed in the WoS database

Authors	Publication Year	Title	Research Area*	Country	Document Type
Trifunovic et al.	2016	*Analysis of semantic features in free-form objects reconstruction*	Computer Science; Engineering	Serbia	Article
Kouzov	2020	*Using Big Data for Solving Big Problems of the Cultural and Historical Heritage*	Information Science & Library Science	Bulgaria	Proceedings Paper
Halamka & Cerrato	2020	*The Digital Reconstruction of Health Care*	Health Care Sciences & Services	USA	Article
Brandenburg et al.	2022	*A Novel Method for Digital Reconstruction of the Mucogingival Borderline in Optical Scans of Dental Plaster Casts*	General & Internal Medicine	Germany	Article
Yan & Xin	2022	*Practical Research on Artificial Intelligence Algorithms, Paleontology, Data Mining, and Digital Restoration of Public Information*	Mathematical & Computational BiologyNeurosciences & Neurology	Peoples R China	Article; Retracted Publication
Steyn & Broekman	2022	*Development of a Digital Twin of a Local Road Network: A Case Study*	Materials Science	South Africa	Article
Katanov et al.	2023	*Digital Core: Temperature Field Influence on Two-Phase Filtration of Fluids in Rocks*	Engineering	Russia	Article
Ceccarelli et al.	2023	*Semantic segmentation through Artificial Intelligence from raw point clouds to H-BIM representation*	Architecture	Italy	Article
Ozturk et al.	2024	*Novel technology use for digital transformation of cultural heritage*	Construction & Building Technology Engineering	Turkiye	Review
Zhang et al.	2024	*Collaborative augmented reconstruction of 3D neuron morphology in mouse and human brains*	Biochemistry & Molecular Biology	Peoples R China	Article

*Research Area: Information available in the WoS database was presented.

According to the results of the bibliometric analysis, only three studies directly focused on the theme of "heritage." Kouvoz (2020) discusses how big data analytics can be used for the conservation and management of cultural and historical heritage sites, emphasising the role of data-driven approaches in digital transformation. Ozturk et al. (2024) examined the use of innovative technologies for the digital transformation of cultural heritage and evaluated the integration of AI-based methods into digital conservation efforts. Ceccarelli et al. (2023) optimised data processing for cultural heritage structures by developing AI-assisted semantic segmentation methods in the transition from point cloud data to HBIM representation. To reveal the relationality of these studies on the study area, a keyword co-occurrence network map was generated (Fig. 3).

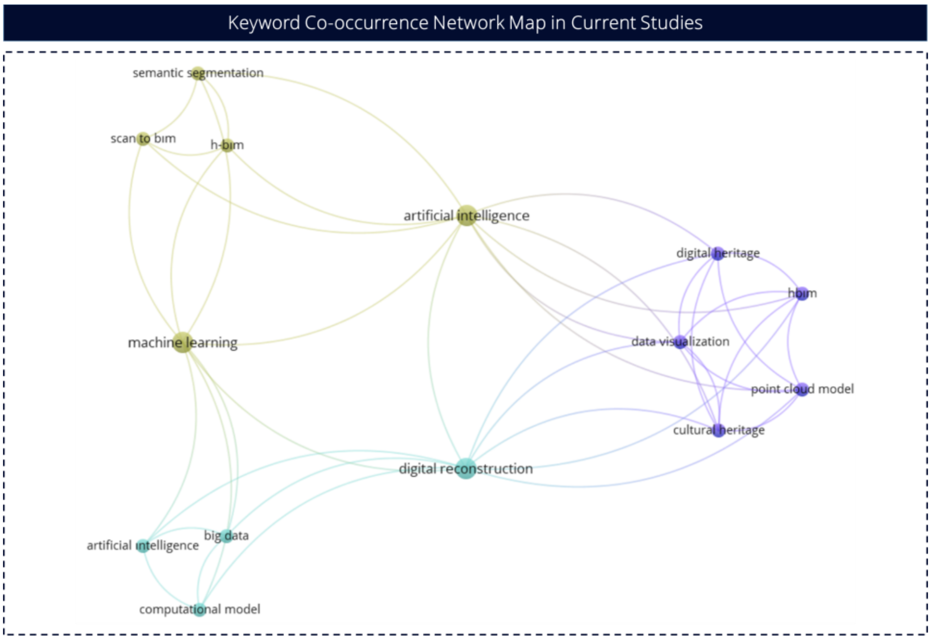


Fig. 3. Keyword co-occurrence network maps a result of bibliometric analysis

The keyword co-occurrence network map from the three studies shows the main themes and ideas related to AI-assisted digital reconstruction in cultural heritage. The study revealed a high level of interaction between the words "digital reconstruction", "artificial intelligence", and "machine learning". Notably, these central concepts relate to more technical and contextual terms like "cultural heritage", "point cloud model", and "semantic segmentation". The study demonstrates that AI-assisted modelling practices have the potential to be integrated not only at the technological level but also in the digital representation processes of cultural heritage structures. However, the limited number of studies representing the term “cultural heritage” in the network also reveals that the research intensity in the field has not yet sufficiently included cultural dimensions. These findings clearly indicate that AI technologies should be integrated into cultural heritage-related processes with more in-depth representations.

3.2. Digital Documentation and Modeling Processes in Cultural Heritage Buildings

This section of the study focuses on the digital documentation and modelling of heritage sites in two different geographic and cultural contexts in Mardin. The first is an example of traditional civil architecture in Midyat, and the other is the ancient city fortification wall of Dara, an archaeological site in the countryside. The traditional house documented in Midyat has unique characteristics in terms of the region's stone architecture, ornamentation, and materials used. The northern fortification wall in Dara, on the other hand, is significant because it belongs to the Ancient Roman period and reveals the local materials and textures of the region, as well as the architectural formation for defence. Due to the presence of heavily damaged and collapsed sections of civil architecture and the fortification wall, it has become essential to document their current condition with high-accuracy digital modelling.

The modelling process required separate fieldwork for both areas. The PhotoScan program developed by Agisoft was used in the modelling process for both areas. PhotoScan allows one to create a 3D model by aligning photographs taken from different angles with a depth-sensing algorithm. The first fieldwork involved taking 383 photographs of the traditional house from various angles. The photos were added to the Photoscan program. The program identified and aligned 379 of the added photos and created a point cloud model. After the creation of the point cloud model, a dense point cloud was created with the “build dense cloud” command, which is automatically defined in the program. With the generation of the dense point cloud, the “build mesh” command was run to build the mesh model. After the mesh model was formed, the "build texture" command was run to integrate the textures in the photographs into the model, and the textured model generation process was completed (Table 2).

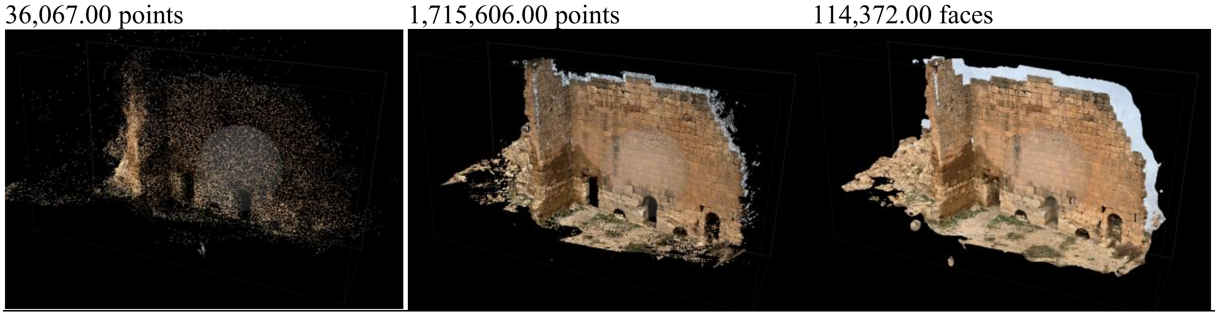
Table 2. Digital model generation process of a traditional Midyat house

Point Cloud Model	Dense Point Cloud Model	Textured Model
141,931.00 points	29,322,297.00 points	1,827,577.00 faces

The second field study involved the modelling of the fortification wall located at the end of the Agora in the northern direction in Dara. To create the model, 42 photographs were taken for the northern fortification wall, and all 42 photographs were aligned by the program to create a 3D digital model. Initially, the program generated a point cloud model, followed by a dense point cloud. Finally, a textured model was produced, and the digital documentation process was completed (Table 3).

Table 3. Digital model generation process of the Dara Fortification Wall

Point Cloud Model	Dense Point Cloud Model	Textured Model
36,067.00 points	1,715,606.00 points	114,372.00 faces



Modelling processes are not only limited to the production of visual documents but can also provide multi-layered contributions in terms of pre-reconstruction evaluation and digital archiving. The digital models produced within the scope of the study constitute a data set for the AI-assisted reconstruction process.

3.3. AI-Assisted Digital Reconstruction from 3D Representations

In this section, the process of AI-assisted visual reconstruction on digital models of cultural heritage buildings was discussed within the framework of two different AI models. The first artificial intelligence model is the DALL-E 3 Inpainting AI model that performs text-to-image generation. With this AI model, it is aimed to visualise the undestroyed and original conditions of the buildings whose digital models were created by performing a prompt engineering process. The second model is Photoshop Beta's "generative fill" AI, which can automatically fill, change, or complete missing areas with content by defining the area you select on an image with text. With this model, it is aimed to complete the demolished and damaged areas of the buildings over the existing photographs of the buildings by AI in accordance with the original structure. This process also provides an opportunity to comparatively evaluate the productivity capacity of two different AI models in terms of both data generation and verification.

With the first AI model, the images obtained from three different 3D digital models of the traditional house in Midyat and the North fortification wall of Dara were uploaded to DALL-E 3 Inpainting and production were performed by writing "prompts" that define the original state for each image. ChatGPT-4o software, an AI tool developed by OpenAI, was also used in the prompt engineering process.

- For the Midyat traditional house *"Using the uploaded photogrammetric images of a historical house, some parts of which have been demolished, taken from different angles. Reference the photogrammetric images I uploaded. Complete the missing parts of the historical building in the black background based on its original architectural style, materials and structure. Preserve the authentic stone textures, window forms and traditional building details typical of 19th-century Mardin's traditional housing architecture. Avoid adding any modern elements"* prompt was used.

- For the Dara fortification wall *"Using the uploaded photogrammetric images of a ruined city wall from multiple angles as reference, reconstruct the missing sections of the wall in accordance with its original architectural style, materials, and structural logic. This wall belongs to the ancient fortifications of Dara Ancient City, located in Southeastern Anatolia (present-day Mardin, Turkey), dating back to the Late Roman–Byzantine period. Avoid introducing any modern elements. The reconstruction should reflect authentic military architecture from late antiquity, characterised by high-quality stonemasonry and monumental proportions. Complete the wall seamlessly based on the referenced visuals, preserving historical accuracy and photorealism"* prompt was used.

At the end of this process, outputs for each building were obtained (Fig. 4). The model can analyse textual inputs and data sets together. Natural language processing and image synthesis algorithms are used in an integrated manner. In this context, DALL-E has the capacity to make sense of not only a descriptive text but also a historical-architectural context and transform it into a new visual output. Through visual comparisons, this dataset provided the opportunity to analyse the potential and limitations of generative AI in terms of the formal integrity of buildings.

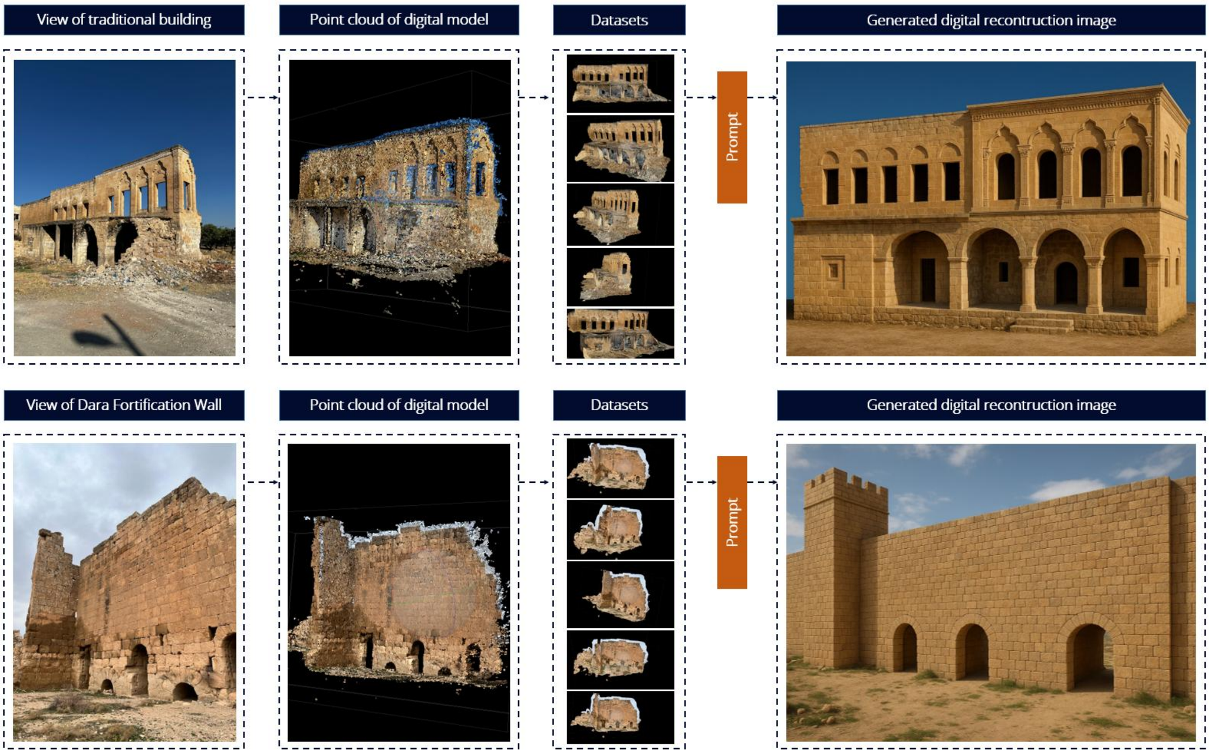


Fig. 4. Reconstruction images from digital model datasets with DALL-E 3 Inpainting

In the second AI model, the photographs of the same structures taken from the field study were imported into the Adobe Photoshop Beta program. Then, for each of them, a prompt engineering process was conducted, and AI-assisted visual completion processes were applied. ChatGPT-4o software, an AI tool developed by OpenAI, was also used in the prompt engineering process.

- For the Midyat traditional house *"Reconstruct the missing parts of the traditional Midyat stone house using limestone, windows, thick walls and roof elements. In the process, preserve the original window openings, arches and facade proportions by referencing the building remains in the image. Match the texture and structural rhythm. No modern materials. Provide 3D volume to match the original texture"* prompt was used.
- For the Dara fortification wall *"Reconstruct the missing parts of the ancient stone fortification wall using the existing architectural and structural features in the image as a reference. Use matching limestone textures, rusticated surfaces, and original fortification wall forms typical of Late Roman-Byzantine fortifications. Avoid modern elements. Complete the wall authentically and seamlessly"* prompt was used.

Photoshop Beta's generative fill feature created new textures in the damaged areas by correlating the prompt used with the visual context. During this process, AI not only analyses the texture, light-shadow distribution and perspective of the existing image but also produces realistic and holistic visual outputs by placing the prompt in an architectural context. Photoshop Beta's generative fill tool is characterised by its capacity to produce a more controlled and environmentally contextualised image, especially when completing defective or damaged areas (Fig. 5).

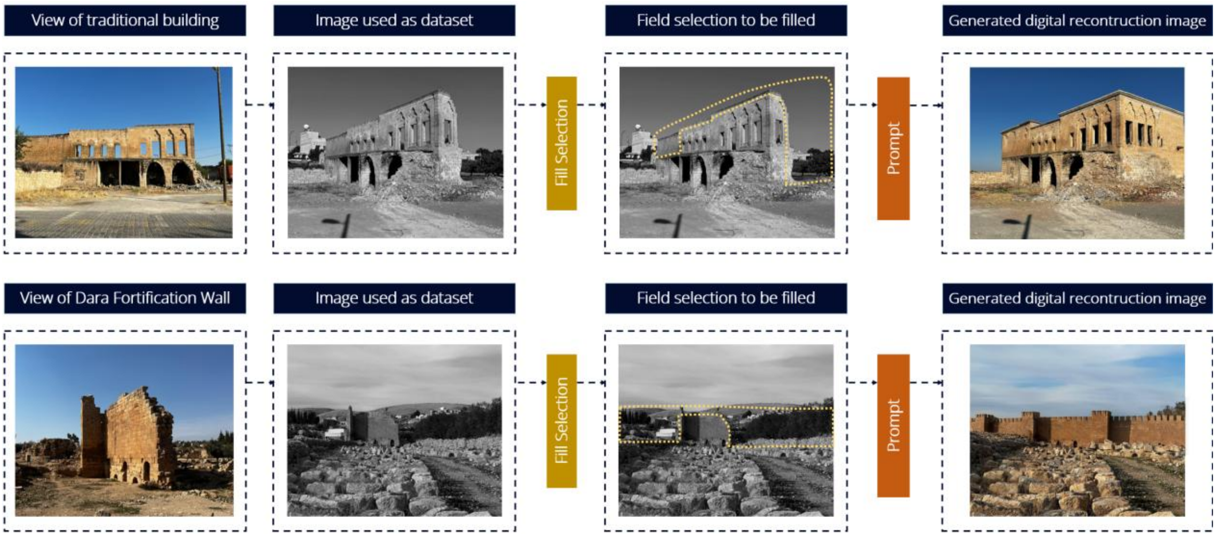


Fig. 5. Reconstructing images from photos datasets with Photoshop Beta

Although the methodological difference between DALL-E 3 Inpainting's ability to produce from scratch and Photoshop Beta's ability to complement the existing image is obvious, both tools offered different levels of intervention and representation. These two AI models can help recreate damaged parts of heritage buildings, explore different possibilities and assess how representative these new images are of the originals. Artificial intelligence can help create digital images of historical buildings, improving how visitors experience them, especially when it's difficult to preserve the actual structures. However, the process of interpreting the resulting images requires not only algorithmic accuracy but also consideration of heritage-orientated evaluation criteria, such as historical authenticity, formal similarity, and consistency.

4. Evaluation and Discussion

The literature reviews and bibliometric analysis conducted in this study indicate that the use of AI technologies in the field of cultural heritage is increasing. However, much of this increase is focused on technical applications, and the basic principles of heritage conservation, such as cultural context, authenticity, and ethical verification mechanisms, are not sufficiently discussed. This situation reveals that AI-assisted digital reconstruction research in the field of cultural heritage is still underdeveloped. Despite the preservation, documentation, and reconstruction opportunities offered by digital technologies in cultural heritage sites, it's noticeable that most of the existing research is focused on fields such as biomedical engineering, road infrastructure, and energy engineering. It is clear that AI applications in areas with unique cultural heritage contexts have not yet reached a sufficient conceptual framework and depth of application. Existing studies have focused on technical issues, such as data management, semantic segmentation, and digital transformation strategies.

Digitisation and modelling processes of heritage sites provide data production that can be integrated into different fields. Survey-restoration studies can be conducted through the models, as well as process-follow-up analysis studies, cultural-urban landscape studies, and structural analysis processes that can be performed in light of these data. The digital models produced in the study not only prepared the basis for AI-assisted production stages but also served as a high-accuracy archive in documenting the current status of cultural heritage assets. Documentation of historical buildings on digital platforms can be considered an important method for the sustainability of heritage, especially in areas where physical intervention is not possible or inconvenient.

Developing technologies in the twenty-first century have also improved the tools used in documentation studies. Unmanned aerial vehicles (UAVs), one of these tools, enable the production of 3D models by taking images from heritage structures that are difficult to access. In this way, the necessary data for research can be produced without the need for physical intervention. The models can be imported into interactive environments such as VR and AR, and a metric virtual platform can be developed for conservation processes. The photogrammetric documentation and 3D digital modelling of the buildings within the scope of the study enabled the detailed recording of both the formal and topological features of the buildings. The point cloud-based modelling techniques used in this process have also visualised the surface features, structural deformations or the extent of future damage. Thus, digital models are no longer just visual representations but have become an analytical resource that provides data-based contributions to intervention planning and reconstruction strategies.

The AI-assisted reconstruction process, conducted after digital modelling, provided the opportunity to comparatively evaluate different production strategies for cultural heritage buildings. In this context, the text-to-image generation realised with the DALL-E 3 Inpainting model produced representations based on the digital model of the existing building. However, these images are produced by taking references from the existing architectural context. Therefore, there is a possibility that the building may be far from the original proportions and architectural data in its original state. This situation reveals that AI should be used for inspirational and idea development purposes, especially in early and rapid production stages. It indicates that detailed restitution studies must be carried out during intervention and decision-making. Despite these limitations, DALL-E's form suggestion capacity and visual completion skills contributed significantly to developing an intuitive perspective on the original architectural style of the building. On the other hand, Photoshop Beta's generative fill tool offered a more controlled and building-specific complementarity in terms of allowing reconstruction directly based on the context of the existing image. Photoshop Beta was able to produce more reliable results in terms of environmental integrity and ratio consistency, especially in completing demolished areas through the digital model. Photoshop Beta cannot produce effective results when completing the image due to the large scale of the structures in the study and the presence of parasites around them. For this reason, Photoshop Beta is expected to produce more effective results for small-scale damages like cracks, moisture, stone spillage, and fractures. However, the historical accuracy of the images produced by both DALL-E 3 Inpainting and Photoshop Beta should not be regarded as certain. The quality of the outputs produced is directly related to the diversity of the dataset on which the model is trained, the capacity of the algorithm used to establish visual logic, and the level of clarity contained in the prompt. AI models produce probabilistic representations by inferring from existing data (Fig. 6). However, these productions should be considered as a vision offering suggestions rather than a scientific representation unless they are supported by restitution principles, archaeological traces, and archival documents.

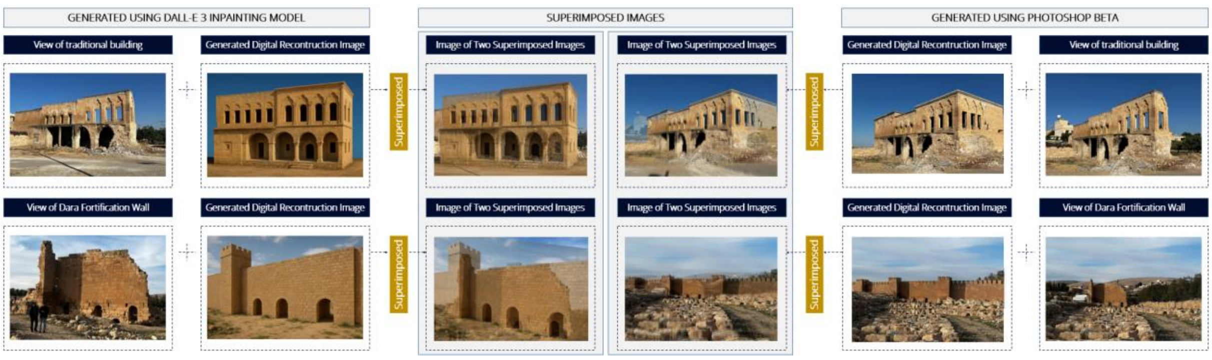


Fig. 6. Superimposing the current state images with the generated artificial intelligence-assisted digital reconstruction images

All these findings and evaluations reveal that the interaction between digitalisation, AI, and cultural heritage requires redefinition not only at the visual but also at the methodological, theoretical, and ethical levels. Digital models and AI-assisted reconstruction practices are creating new areas of responsibility within the conservation discipline. The creation of digital twins of cultural heritage enables not only the production of physical data but also the construction of historical memory through multiple representations. In this context, it is essential to consider not only the development of digital reconstruction tools but also the principles of cultural, historical, social, and ethical verification that will govern their use.

5. Conclusions

This study reveals the applicability, limitations, and potential of AI-assisted digital reconstruction processes in the field of cultural heritage within the framework of a multi-layered analysis. Bibliometric analysis has revealed that, although the concepts of digital reconstruction and AI are rapidly gaining place in scientific literature, cultural heritage has not been sufficiently integrated with these technological developments. The limited number of such applications primarily focus on technological disciplines and healthcare. They are not yet supported by ethical and interdisciplinary approaches shaped according to the requirements of the historical and cultural context.

The digital documentation and modelling of the traditional house in Midyat and the fortification wall in the ancient city of Dara, located within the borders of Mardin, can be considered as concrete examples of applications in the field of technology and heritage. The representations generated by the point cloud-based modelling process also served as datasets that could be considered references for AI-assisted reconstruction applications. Generative AI tools, such as DALL-E 3 Inpainting and Photoshop Beta, interacted with these models to produce alternative completions and visualisations, which proved to be an effective method, especially for early decision-making processes and idea development stages. However, the outputs of these tools do not meet the standards of scientific preservation in terms of historical accuracy and contextual appropriateness. Therefore, AI-assisted digital reconstruction methods should be evaluated only in terms of generating visual suggestions and providing intuitive analysis. Archaeological traces and visual archival documents should support restitution principles before using them as a final decision-making tool. Nevertheless, the rapid development of these technologies indicates that much more effective and reliable representations of cultural heritage can be produced in the future.

As a result, this study presents an original example of the integration of digital technologies and generative AI in the field of cultural heritage. Through an applied field study, an assessment of both modelling and AI-assisted visual production processes is conducted. This approach provides a suggestion that decision-making mechanisms in conservation practice can be assisted by digital tools.

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Preliminary research on two ancient aqueducts in the fortress of Amasya

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Abstract. Amasya, located in north-central Anatolia, was founded in the valley where the Yeşilırmak River flows. Archaeological findings suggest that it has been continuously inhabited since the Neolithic Period. The earliest known communities in Amasya are the Hattians (3000 BC) and Hittites (2000 BC). The most glorious period of Amasya in its history was the Hellenistic Pontus Kingdom, which ruled in the 2nd-3rd centuries BC, when it was the capital of this state. The remnants of this period are still visible in the city's cultural hubs, including fortress of Amasya, in the present day.

Overlooking the valley where the city founded, the Amasya fortress is situated on Harşena Mountain, which is located on the northern side of Yeşilırmak. It is regarded to date back to the Bronze Age and has been occupied continuously throughout its history. The oldest architectural remains in the fortress today date back to the Hellenistic Period. While the community on Acropolis hill relied on cisterns and stepped tunnels, which were constructed in various periods, to meet its water needs, the lower settlements benefited from the development of aqueducts.

This research focuses on Karaman and Helkıs aqueducts, two ancient aqueducts located on Harşena Mountain where the fortress of Amasya was built. For this purpose, architectural characteristics, the construction techniques, and the locations of the aqueducts have been investigated. Additionally, the springs of the aqueducts and the destinations they were constructed to supply for discussed. Finally, evaluations were made regarding the period in which the structures in question were built and their effects on the development of the settlement.

Keywords: Fortress of Amasya; Mount Harşena; ancient; aqueduct

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1. Introduction

According to Thales, water, which is the "*arkhe*" of everything (Kranz, 1994), is one of the basic substances that ensure the continuity of life on earth. Being a source of life has made it one of the most important elements determining the settlements of human beings since prehistoric times (Ramsay, 1960). However, many and various types of water structures have been built in these settlements in order to meet the need for water.

Founded in the center of North-Central Anatolia, in the valley where Yeşilırmak gives life, Amasya has a history of approximately 8000 years. Archaeological researches conducted in Doğantepe Village of the center revealed remains dated to the Neolithic Period (Özdemir, Uçar, Mecek, & Yılmaz, 2007). The Hatti Period artifacts discovered in Mahmatlar Village of the center and called Mahmatlar Treasure (Koşay & Akok, 1950) and the statue of the Hittite Storm God Teşup (Alp, 1961) found in Doğantepe are important findings that point to the settlement history of Amasya in the 2nd and 3rd millennium BC. The presence of Scythian and Median communities in the city is mentioned until the Persian domination (Achaemenid Empire) which started in 546 BC. According to Strabo, the city was the center of the 19th Persian Satrapy during the Persian rule that lasted for about 2 centuries (Strabo, 2000). Important finds related to this period in the city are the Persian Road uncovered during the excavations at Oluzhöyük, a place of worship and the first known firepit of Anatolia (Dönmez, 2018). Amasya entered the borders of the Cappadocia Pontica State (Katpatuka) in 360 BC and became the first capital of this state in 281 BC. During this period, intensive construction movements occurred in the city and rock tombs, walls, bridges, altars, temples, cisterns, stepped tunnels and aqueducts were built (Strabo, 2000).Amasya Fortress is the place where the textures of the Hellenistic Period can be observed the most in Amasya today.

Although the recent excavations in Amasya Fortress yielded objects dated to the Early Bronze Age (3000-2500 BC) (Naza-Dönmez, 2012), the earliest surviving architectural textures belong to the Hellenistic Period. The

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fortress consists of 3 levels depending on the elevation of Mount Harşena on which it is located. These are the acropolis at the top, the Kızlar Palace and the rock tombs in the middle, and the part on the banks of Yeşilırmak, which is today called İçerişehir. In these regions, which are known to have been inhabited without interruption, palaces, residences, baths, religious and military buildings were built from various periods, and cisterns, stepped tunnels and aqueducts were built to meet the water needs of the users (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017) (Aykutlu, 2023). Karaman and Helkıs Aqueducts, which are the subject of our study, are water structures built to meet the water needs of these settlements in Amasya Fortress in the historical process.

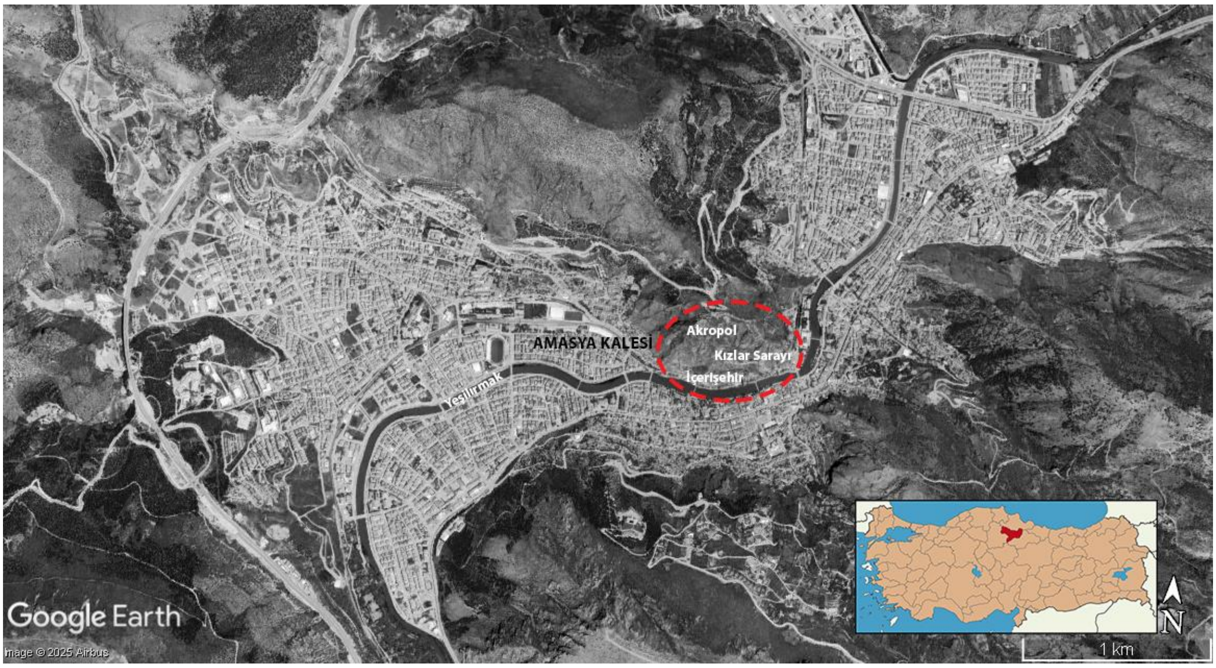

Fig. 1. Amasya, Settlements of Amasya Fortress on Mount Harsena

2. Findings

2.1. Karaman Aqueduct

2.1.1.. Location and Course

Karaman Aqueduct is the transmission line that delivers water to the İçerişehir district, which is the lowest settlement of Amasya Fortress and located on the banks of Yeşilırmak. It was carved into the rocks on the slope of Mount Harşena, north of the railroad that passes through here.

According to Göztaş et al. the source of Karaman aqueduct is located in Yuvacık Village (Karaman District), 3.3 km northwest of the Fortress. Today, the water source continues to flow with a flow rate of 15-30 l/sec in a pool arranged under the Şeyhcui Baba Mosque in the center of Yuvacık Village. There is also a water trough carved into the monoblock rock in front of the mosque with grooves on the sides. It is believed to be a part of the Karaman water transmission system with the function of water distribution (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017) (Fig.2).

The best preserved parts of the Karaman Aqueduct were found on the cliffs of the Kurşunlu Quarter in the western neighborhood of Amasya Fortress. From here, the canal, which continues towards the Fortress by carving openly into the rocks, pierces the walls and continues for about 1 km along İçerişehir and cannot be observed after the registered building, which is used as the Municipal Guest House today, due to the destruction caused by time. Amasya Museum Director Özdemir states that in its original form, the Karaman Aqueduct terminated at the Büyük Kaya Cistern about 100 m east of the Guest House, where the water left over from the distribution was stored (Özdemir, 2001) (Fig. 3).

Fig. 2. Karaman Aqueduct, Source and Taksim Stone (Aykutlu, 2023)

Fig. 3. End of Karaman Aqueduct, Büyük Kaya Cistern

The parts of the aqueduct continuing to the source in the west direction after the Kurşunlu Quarter cannot be observed. Göztaş et al. (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017) state that The aqueduct originating from the site of Karaman Mountain initially extended through underground terracotta pipelines, then it was built as a masonry covered canal until it passed the necropolis northwest of the Kurşunlu Quarter. As a matter of fact, during the interviews conducted during the fieldwork, it was stated that the terracotta pipelines mentioned by Özdemir were found in some construction foundations in the Şeyhcui neighborhood, which is the entrance area of the canal to the city after Yuvacık Village. In addition, it was learned that the water of Hızırpaşa (Sümbül) Bath House, located between Yuvacık Village and Kurşunlu Neighborhood, came from this source in previous periods.

Based on this information, distance and elevation values were calculated. Accordingly, it was determined that the distance between Hızırpaşa Bath and the point where the canal terminates in İçerişehir is 1600m and the elevation difference between these two points is approximately 15m. As a result of the calculations, it was found that the Karaman aqueduct has a slope of 0.0093 (0.93%) between the mentioned points. This is in accordance with the suggestion of Vitruvius in the ancient period.[1]

There is a great elevation difference of 140m at a distance of about 2km between the bathhouse and the spring. There are two possibilities here: Either the aqueduct maintained the same slope for some time after the bathhouse and then steepened too much - there must have been different systems integrated into the aqueduct to balance the pressure - or the slope must have increased after the bath and continued with this slope until the spring.

According to the Amasya Museum, the remains of a fountain were found on the Karaman Aqueduct. The fountain, which was carved into the rock, was supplied with water from the Karaman Aqueduct through a smooth vertical groove that provides direct flow from the Aqueduct, and this groove ends with the gutter of the fountain. On the central axis of the flattened rock surface where the vertical groove is located, a cross motif was carved into the rock. On both sides of the flattened surface there are two square holes drilled in a regular quadrilateral form. There is also a trace of a 3-step ladder on the right side of the rock block where the fountain is located (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017). It was recorded that the fountain on the Karaman Aqueduct was provided with a small and continuous flow of water from the aqueduct in its original condition (Fig. 4). No fountain was encountered during the on-site surveys of this research.

[1] Vitrivius recommends that the slope of aqueducts should be 1 meter or more per 200 meters (Vitruvius, 2015)

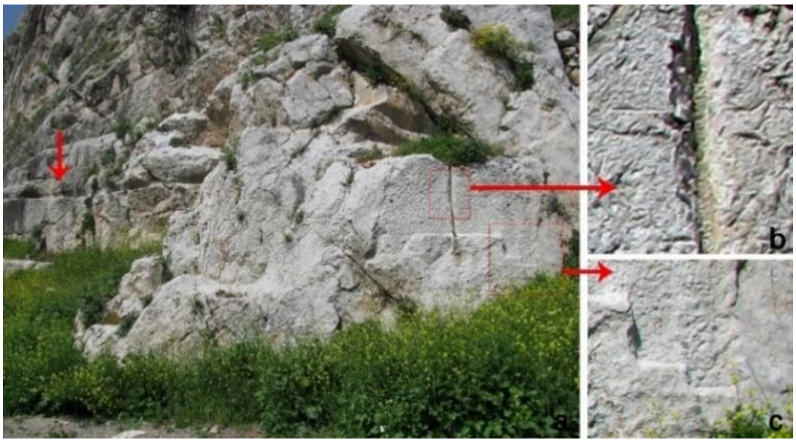

Fig. 4. Karaman Aqueduct, Fountain Remains

2.1.2.. Technic and Architecture

It can be assumed that Karaman Aqueduct was constructed with 3 different techniques along its route starting from its source in Yuvacık Village: The terracotta pipeline organized under the ground in the initial parts, the masonry covered channel in the middle parts, and the section carved into the open rock near the Amasya Fortress (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017). Of the entire transmission line, only the part carved into the open rock can be observed today due to construction and being under the ground.

During the on-site investigations, the last parts of Karaman Aqueduct, which were carved into the rock, were encountered. These parts start from the slopes of Mount Harşena to the northeast of the Kurşunlu neighborhood, continue eastward to İçerişehir and end at a point close to the Büyük Kaya cistern after entering İçerişehir by piercing the city walls. It was observed that the channel was carved into the rock with a very neat workmanship in the vicinity of Kurşunlu Quarter. The base width of the channel was measured as 15-20 cm and the height as 30 cm. The net height of the deep part that holds the water is 18-20cm.

Fig. 5. Karaman Aqueduct, Rock-cut Sections Through the Fortress

Today, differences were observed between the remains of the canal due to the destruction of the canal over time. In the better preserved remains, it was observed that on both sides of the canal, 18-20 cm high and 6-10 cm wide benches were formed. It is understood that this arrangement was made to cover the canal with cover stones (Fig. 7-8). As a matter of fact, similar arrangements to protect the water from external influences are known both in Anatolia and in the historical aqueducts in Amasya (Aykutlu & Kara-Pilehvarian, 2024). Traces of the rock-carving workmanship of the Karaman Aqueduct can be found close to the Fortress walls. It is understood that the rocks were carved with a chisel-like tool (Fig.7).

The construction date of the Karaman Aqueduct, which is the highest capacity water transmission line known to the old settlement area known as Amasya İçerişehir, is not certain. Mustafa Vazıh Efendi, the first Amasya city historian, states in his work that the Seljuk Sultan Sultan Abû Saîd Mes'ud brought water from Şeyhcui and Kavaklı (Karaman) for his palace and settlements in İçerişehir (Mustafa Vazıh Efendi, 2014). If what is meant here is the Karaman Aqueduct, it seems more plausible that Sultan Masoud utilized this aqueduct for his palace in İçerişehir, rather than building it during the Seljuk Period as M. Vazıh states. Because both the rock-carved structure of the aqueduct and the history of its destination indicate that it was built long before the Seljuk rule. Although there is a possibility that this aqueduct may have been a new aqueduct other than the Karaman aqueduct built for the Seljuk palace, no trace of such a aqueduct has been found so far.

Göztaş et al. suggest that the aqueduct was built in the 4th century BC (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017). Considering that the Achaemenid Empire, which included Amasya, was divided in the 4th century BC (360 BC) and the city remained within the borders of the Pontic Cappadocian State afterwards, it is possible that there may be hesitation as to whether the Karaman Aqueduct is an Achaemenid or Pontic Cappadocian Period work. However, considering that the city experienced its most brilliant period during the Pontic Kingdom period with the title of capital and that many construction activities were carried out in the city during this period, it seems more reasonable that the Karaman Aqueduct was built during the Hellenistic Period Pontic Kingdom Period.

Fig. 6. Karaman Aqueduct, İçerişehir

Fig. 7. Karaman Aqueduct, Kurşunlu District ve Chisel Marks

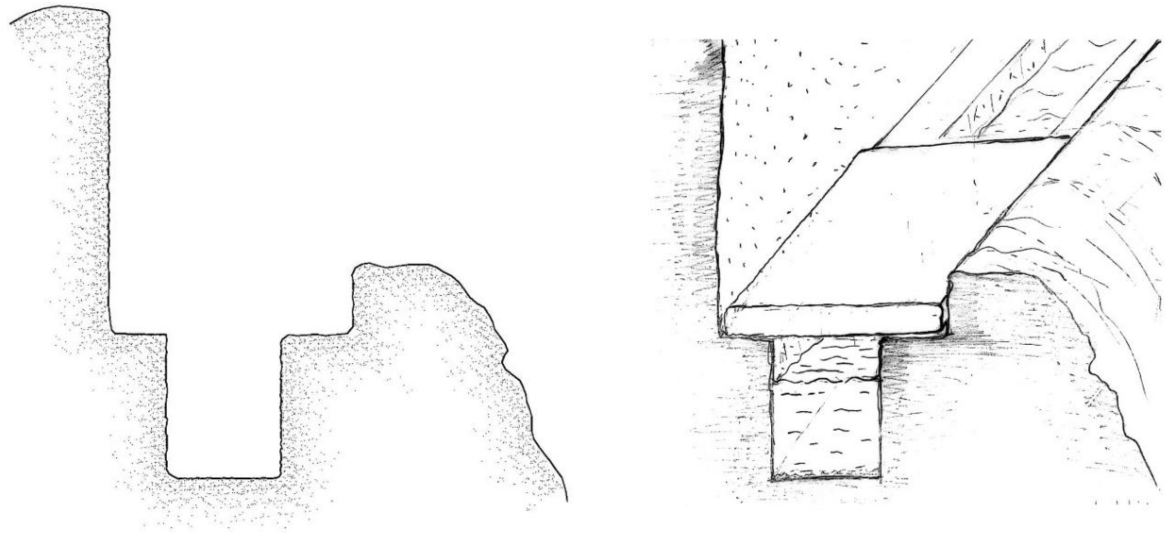

Fig. 8. Karaman Aqueduct, Survey and Reconstruction

2.2. Helkıs Aqueduct

2.2.1. Location and Course
Lennep, who visited Amasya in the 2nd half of the 19th century, noted that a water channel was built on the eastern side of the valley where the Fortress is located, by carving rocks in front of the hard rocks. The said canal, which he stated continued for about 3 miles (about 4.8 km) at that time, must have been the Helkıs Aqueduct (van Lennep, 1870).

Helkıs Aqueduct was located at a level between the Acropolis Hill of Amasya Fortress and the *Kızlar* Palace and its remains can be seen today on the northern and eastern slopes of Mount Harşena. Göztaş et al. state that the canal was built to convey water from a water source on the eastern slopes of Kırklar Mountain to the *Kızlar* Palace (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017).

Today, the rock-carved parts of the Helkıs Aqueduct can be traced for about 1 km on the northern slopes of Mount Harşena. Göztaş et al. suggest that it conveyed water to the *Kızlar* Palace and ended at the corner of the rock grave no. 1 near the *Kızlar* Palace. It is also reported that there is a cistern on the route of the canal north of the Fortress, which is currently used for agricultural irrigation purposes, and it is not known whether the cistern is related to the canal or not (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017).

During the on-site investigations, it was determined that the Helkıs aqueduct is located at +540 on the northern slopes of Mount Harşena, while the location of the *Kızlar* Palace is at +440 levels and there is a level difference of approximately 100 meters between them. As a result of the calculations, it is understood that the aqueduct could not have been built in relation to the *Kızlar* Palace as it has a slope of 0.96%. The level of the aqueduct passes just below the *Top Kulesi* in the lower levels of the Fortress. The Helkis Aqueduct must have been built to serve other buildings between the Acropolis Hill and the *Kızlar* Palace. At this level, especially on the western slopes of the Fortress, the remains of some buildings can be recognized.

A water tunnel was identified on the eastern slopes of Kırklar Mountain called Yiğitoğlu Forest and near the İhsaniye Neighborhood. The entrance of the tunnel is about 2.5 meters below the ground level and today it is covered with a reinforced concrete cover. The walls of the tunnel, which continues under the ground, are built of rough masonry stones and covered by a triangular vault built of rough masonry stones. The tunnel is about 70 cm wide and 1.5 m high, and although the base of the tunnel is covered with vegetation, Yavuz Tokmak, the former headman of Ihsaniye Neighborhood, who guided the fieldwork, stated that a channel-like arrangement about 25 cm wide continues at the base during the cleaning works. Approximately 15 meters up from the tunnel mouth, a well-like structure was encountered which seems to be in line with this line. It is thought that the structure, which was built of large rough masonry stones similar to the tunnel, may be an air shaft built in relation to the tunnel by opening to this water tunnel (Fig 10).

2.2.2.. Technic and Architecture
During the field study, it can be concluded that Helkis Aqueduct was constructed with 2 construction techniques; open rock carving and underground masonry structure. In addition, terracotta pipes were also found in situ (Fig 11). A layer of mortar can be observed at the joints of the pipes with an average length of 46 cm. This layer must

be the layer of *lökün* applied for insulation purposes at the joints of the terracota pipes during the Ottoman Period (Çelik , 2009). It is believed that this pipeline was constructed during the Ottoman period when the canal was idle in order to convey the water of the spring to the structure known as the Yukarı Türbe or Şirvanlı İsmail Türbe. As a matter of fact, this transmission continues partially today with plastic pipes.

The base width of the channel was measured as 19-22 cm and the depth as 25-27 cm in the rock-carved sections. In the part on the slope, an average depth of 60 cm was opened and the channel was formed. No bench-like arrangement was found within the channel (Fig 12).

Göztaş et al. state that the Helkıs Aqueduct, a significant part of which has disappeared today, was built by the Pontic Kingdom in the 4th century BC during the Hellenistic Period and was used until the end of the Ottoman Period (Göztaş, Doğanbaş, Özdemir, & Mesci, 2017). The technical and architectural features of Helkıs Aqueduct, which is examined within the framework of this study, are similar to the Hellenistic Period aqueducts. In addition, considering the historical geography of the city, it is thought to have been built during the Pontic Kingdom Period of the Hellenistic Period, when there was significant construction in Amasya Fortress.

Fig. 9. Helkis Aqueduct on the North and East Slopes of Mount Harşena

Fig. 10. Water Tunnel and Well at Helkis Spring

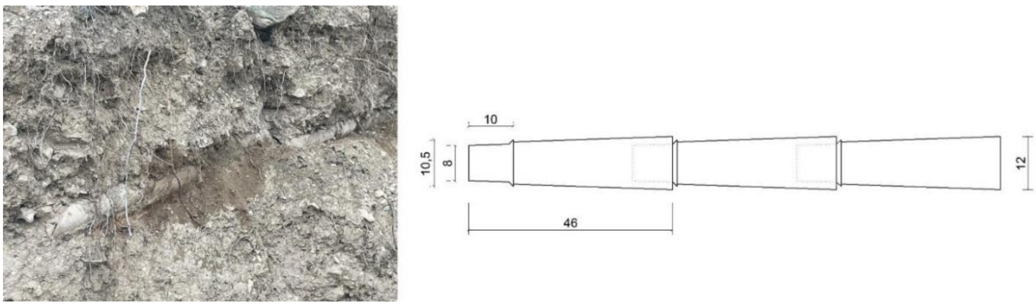

Fig. 11. Helkıs, Terracotta Pipes

Fig. 12. Helkıs Aqueduct, Details

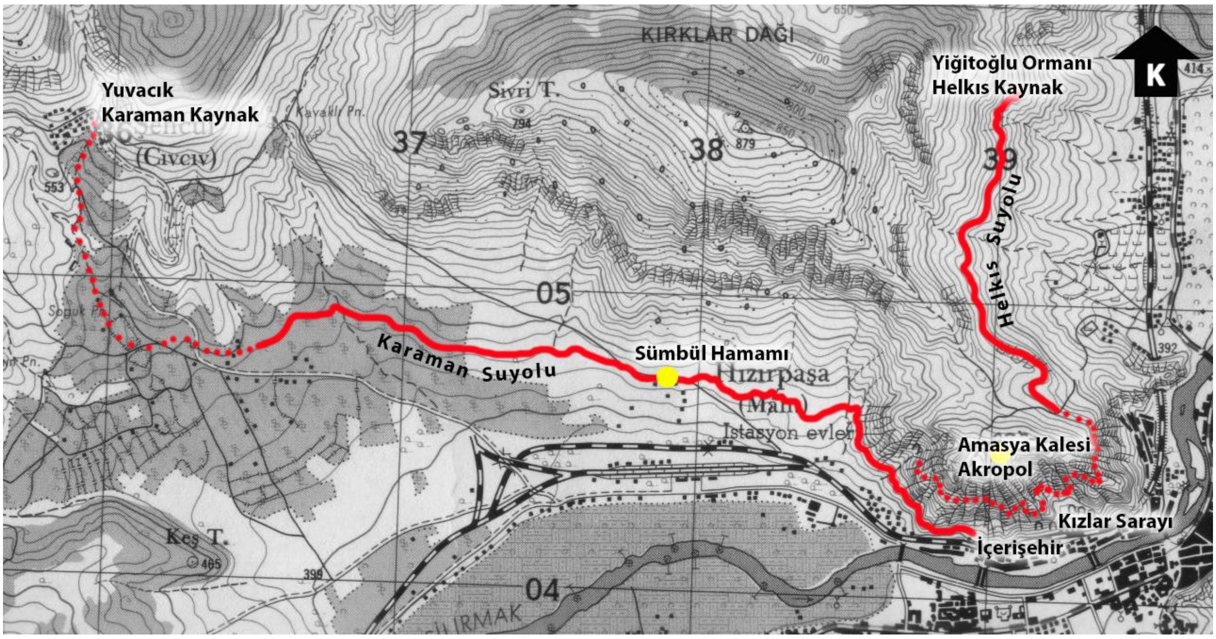

Fig. 13. Karaman and Helkıs Aqueducts in Amasya

3. Conclusions

In addition to the water resources that Amasya has had since the Neolithic Period, the influence of the Harşena Mountain, which is extremely suitable for building a Fortress as a defensive structure, is undeniable. From the foothills of Mount Harşena on the banks of Yeşilırmak to the Acropolis hill, a significant part of Amasya Fortress has been the construction area of Amasya Fortress throughout history. Cisterns, stepped tunnels and aqueducts were the water transmission structures that fed these settlements.

Karaman and Helkıs Aqueducts, which were examined within the scope of the study, are the structures that transmit water to Amasya Fortress from the east and west. Both of them have mixed structural systems such as rock-carved and masonry. It is thought that the Karaman Aqueduct, which was built with the optimum slope accepted in the ancient period, served the settlement on the banks of Yeşilırmak, while the Helkıs Aqueduct served the settlement between the Acropolis and the *Kızlar* Palace and closer to the Acropolis.

Considering the construction techniques and the historical geography of Amasya, it is understood that these structures were built during the Pontic Kingdom Period of the Hellenistic Period, when the city experienced its most brilliant period and received the title of Metropolis. The results of the research once again reveal the physical development and especially the vitality of the Fortress settlements in Amasya during the Pontic Kingdom.

Although these water structures, which fed the settlements of Amasya Fortress for centuries from the Hellenistic Period onwards, are inactive today, the springs from which they were fed are still actively serving life.

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Masculine spaces and feminine spaces in rural settlements: The case of Ankara Çamlıdere

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Abstract. In rural settlements, public spaces are shaped according to production dynamics, local materials, period technology, mastery knowledge, and traditions. In these places, individuals who come together for a specific purpose achieve this purpose by sharing information and socializing. In rural settlements, spaces that align with gender roles attract attention. This study focuses on masculine and feminine spaces in rural settlements, which differ under the influence of production dynamics and are shaped in line with gender roles. Masculine spaces are areas such as village rooms and coffeehouses where men are more visible daily. Feminine spaces are places such as bakeries, fountains, and laundries, which are shaped around tasks that are under women's responsibility and where women take an active role in the production and sharing processes. This distinction reflects the structure of rural life based on production and social division of labor. These places in social memory are essential in understanding rural settlements' cultural and social structure. Analyzing masculine and feminine spaces is valuable for preserving architectural heritage and social memory. Conservation efforts should consider the functional and cultural identities of places and their physical structures, considering their place in social memory. This study examines the typologies of masculine and feminine spaces in rural settlements with the perspective of preserving their physical and social functions. With the literature review and field study method, the dimensions, features, locations, relations with gender roles, and transformations of the spaces from past to present are discussed.

Keywords: Çamlıdere, Rural Architectural Heritage, Public Spaces, Masculine Spaces, Feminine Spaces.

1. Introduction

Studies on the documentation and protection of rural architectural heritage, which is included in the "endangered heritage" list prepared by UNESCO, have gained momentum. To keep cultural heritage alive without disappearing, it is essential to document and reveal the rural architectural heritage in different geographies of Türkiye without losing its originality. There are original examples of rural architectural heritage in the villages of Çamlıdere district of Ankara. These villages have settlement characteristics suitable for topography and climate conditions. Structures ideal for daily life practices were built with rational and practical solutions in the light of material knowledge and mastery accumulation. These structures constitute a valuable heritage regarding environmental sustainability and social context. The biggest reason for this rapid disappearance is the migration of villages. The number of people in the villages is decreasing. The best-preserved structures among the structures examined within the scope of rural architectural heritage in the district are the houses. Even if they are not used in summer and winter, the villagers, especially those living in Çamlıdere and Ankara, spend time in their villages during the summer months. The common-use areas examined outside the houses are rapidly disappearing. The decrease in the village population has caused a reduction in the need for these areas.

Gender roles shape public spaces in rural areas. Accordingly, separations are seen in spatial organization. There are also significant differences in the use of space. Masculine and feminine spaces are separated in line with gender roles. Spaces where men and women are visible in daily life emerge. These important architectural structures reflect the cultural and social structure of rural settlements. These are the data sources of social memory.

2. Public Space: Masculine Spaces and Feminine Spaces

The environment is a spatial formation to which it belongs. Space is a structure in which culturally meaningful categories exist in a particular order. These categories are established through specific diseases, place changes, and direct relationships with humans. The environment includes physically structured formal features, social components, and order. For example, while a house reflects what kind of a company it is and its cultural values, a settlement's public and private historical actuality reveals its social lifestyle and cultural codes (Karasözen, 1993).

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The definition of public space has been questioned by many thinkers in the historical process. The concept of public space has been discussed to solve the social structure. Because public space is human-centered and holds various potentials together, it finds a place in interdisciplinary studies today. Especially in terms of architecture, It gives clues about the social structure in analyzing the relations between settlements and their users. Public spaces, which have gained importance in daily life, witness the entire historical process and even become the scene of historical changes. If we need to reach a common idea within the scope of literature studies, it is seen that many thinkers define the public as open to everyone (Özcan Uslu, 2018).

Public space is the area of both cultural symbols and lifestyle practices. Public space is where social values and lifestyles are adopted and reproduced. Public space is the center of social relations (Canaran, 2018). While spaces define areas where individuals continue their lives within the social structure, these areas also reflect gender-related meanings. Different ways of offering freedom, setting boundaries, and providing opportunities to women and men actively shape how space functions. Gender roles shape space and assign it meaning. Researchers have conducted various studies showing that different gender groups experience space differently, that space and gender interact dynamically, and that space actively shapes and reproduces gender roles (Dinçtürk, 2019). People also shape and namespace according to gender, not only in public settings but also within the household. In other words, both public and private spaces are often organized as gender-specific areas (Siwach, 2020).

Historically, the separation of masculine and feminine spaces dates back to ancient times. In ancient times, stoas and agoras, where men socialized in public spaces such as shopping, chatting, and philosophy, were depicted as masculine spaces. In everyday life, it is understood from the depictions of women in public spaces that they were in front of fountains. There are examples where women come to the fountain and chat, and the fountain is described as a gathering area (Fig. 1.) (Açıl, 2018; Canaran, 2018).

Fig. 1. Jewellery box, fountain scene, circa 460 BC, Hydria, women at a fountain, circa 530 BC (Açıl, 2018)

When the distinction between masculine and feminine spaces is examined within the scope of the field study and literature study, feminine spaces are not spaces used entirely by women but spaces where women are present and dominant. Men can also enter these spaces. However, it is seen that women are not included in masculine spaces belonging to men. However, it shows that women are primarily used in spaces described as women's spaces. Men are not excluded in these spaces. However, women do not use spaces described as men's spaces (Siwach, 2020). Public space studies mainly focus on public spaces located in cities. However, public spaces in rural settlements are essential in understanding the relationship between people and space. The definition of public space in rural settlements needs to be made. Although studies continue today, studies on common-use spaces in rural settlements are limited.

3. Çamlıdere Rural Settlements

Çamlıdere is a district of Ankara province that stands out with its natural and cultural values. The entire Köroğlu Mountains are located. It is adjacent to Gerede in the north, Kızılcahamam in the east and northeast, Güdül in the south, and Beypazarı in the southwest. The city is approximately 100 km away. The district is significant because of its forested areas and plateaus. The culture of the people of the region, which is located in the plateau district in a large area, continues today. It has a rugged terrain structure. Çamlıdere, due to its location, has a transition zone between the Black Sea Region and the Central Anatolia Region. For this reason, it has a denser forest area than the rest of Ankara. 52% of the region is covered with forests (Arslan Takcı, 2022; Begiç & Sarıcan, 2021; Sarıcan, 2021).

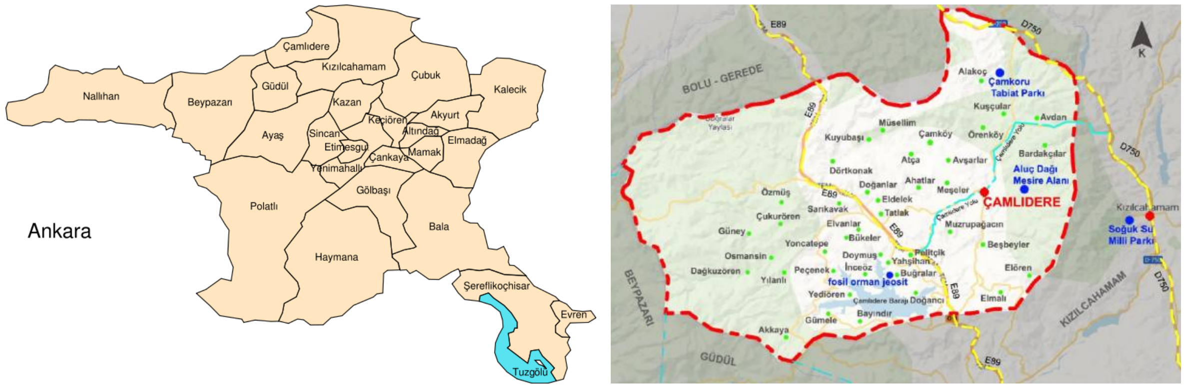

Fig. 2. Ankara province map (URL-1) Villages of Çamlıdere district (Arslan Takcı, 2022)

Çamlıdere district is one of the regions where animal husbandry is carried out due to its forest presence and topography. Animal husbandry and forest products are the most important sources of income for Çamlıdere district (Arslan Takcı, 2022).

Fig. 3. Çamlıdere rural settlements

There are 48 neighborhoods in Çamlıdere district. According to metropolitan law, the settlements with village status have been transferred to neighborhood status (URL-2). A settlement pattern has been created in the villages on sloping land by adapting to the topography. Since livestock farming is a livelihood in the region, places for animals stand out. In addition, since the region has a dense forest area, wood is considered the primary building material. Rural settlements have various places such as houses, mosques, barns, haylofts, sheep pens, woodsheds, village rooms, and schools. However, most of these places are either never used or are used during specific periods of the year. Unused places are idle. With the migrations experienced in rural neighborhoods, the population decreases, and the buildings deteriorate.

Today, in the villages where documentation was conducted within the scope of fieldwork, most houses are used during certain months of the year or are not used at all. It is observed that to provide comfortable conditions in the houses in the villages, new houses are built within the parcel, new reinforced concrete houses are built nearby, or the original houses are demolished and replaced with new houses. This situation negatively affects the rural settlements in Çamlıdere district and many other rural settlements and causes significant damage to the original texture.

The structures in the rural settlements of Çamlıdere district contain many wooden materials due to the dense forest. The structures built with traditional construction techniques are built with the stacking and carcass system. The structures constructed with the stacking system are wood and stone stacking, and the structures built with the carcass system are built with fillings of different materials between the wooden frames. Two types of structures are built with the wooden stacking (cantı) technique, which is densely formed in the region. The first type is the structures of single-story warehouses, haylofts, etc., with different functions developed only with the cantı technique. The second type is generally used as a construction technique in houses, where the first floor is made of masonry and the second floor is built with the cantı system (Sağıroğlu, Toğay and Toğay, 2019).

Fig. 4. Traditional houses in Çamlıdere district

In rural residences in Çamlıdere district, houses are generally built as two-storey. However, the examples of houses with intermediate floors are 3-storey. Ground floors are used for animal living and storage. These floor entrances are generally independent of the living and are provided through single or double-wing doors. In some examples, there is a connection between the ground floor and the living floor. The ground floors of the houses are generally built with a stacked stone system, and the windows are small.

Fig. 5. Çamlıdere Çamköy village traditional housing plan sketches (Sağıroğlu et al., 2019;Arslan Takcı, 2022)

Traditional houses are accessed from the road or the garden. Outbuildings, which are essential elements of rural life in the garden, are located adjacent to the house or close to the house within the parcel. Although structures such as woodsheds, haylofts, warehouses, and chicken coops are not in a designated place within the parcel, they are generally positioned in a way that they are in visual relation with the house. However, haylofts, which are not located within the parcel in the region, are generally placed on sloping areas, and direct access is provided from the upper level.

Fig. 6. Haystacks

4. Masculine Spaces and Feminine Spaces in Ankara Çamlıdere Rural Settlements

Within the scope of this study, the detection and documentation work in the villages was detailed and photographed. These settlements are Ahatlar, Atça, Avdan, Avşarlar, Beşbeyler, Çamköy, Dörtkonak, Kuşçular, Meşeler, Müsellim, Muzrupağacın. Within the scope of the survey carried out in the field, the existence of outbuildings and housing sections, haylofts, woodsheds, and wild animals was determined, although their use is limited. Within the scope of the field study, the focus was on public spaces. In terms of masculine and feminine spaces, the village rooms were masculine spaces, and the fountains and residences were feminine spaces. With the migration of Çamlıdere rural settlement over time, the number of people living in the areas decreases, the population ages, and production activities decrease. With the decrease in population, the demand for spaces used together by the villagers also decreases. The few remaining everyday use spaces are also in the process of becoming obsolete. With changing living conditions, the culture of spending time in shared spaces decreases. For this reason, within the scope of the study conducted in the field, it is essential to come across perhaps the last users who use traditional structures and to obtain information about the places where they spend time together.

In the rural area of Çamlıdere, village rooms are at the forefront among the common-use areas where men spend time. These areas are used only by men, but women do not use them. Also, children do not use these areas. In the interviews conducted with the users who use traditional village rooms, it was learned that since they usually gather in these areas in the evenings, entertainment/games are also played in addition to chatting. Meals are also eaten in these areas. Village rooms, which are places for socializing, are essential among the everyday use areas where the village people spend time together. Village rooms are also open to guests coming to the village. Village rooms are places where travelers who come to the village can stay, meet their basic needs, and be hosted until they leave the village. They are also social spaces where villagers come together, especially in the evenings, to chat, discuss, and play various games. These rooms, which also serve as venues for mass events such as weddings and funerals, are among the rural structures where hospitality and social solidarity are embodied. It is known that the guests coming to the village keep their animals in the village rooms, which usually have a barn on the lower floor. While these rooms are sometimes built by the joint efforts of the villagers, they are often built by the village elders in their names and brought into the village life (Yılmaz, 2023).

The number of village rooms in the villages varies. In some villages, there is one village room, while in some villages, there is more than one village room. For example, in Muzrupağacı village, there are three village rooms. The number of village rooms is classified according to the village size or the number of neighborhoods in the village. If there is more than one neighborhood in the villages, each neighborhood may have its village room. The maintenance and use of that village room is the responsibility of the neighborhood's residents.

Village rooms are generally close to the village square and/or mosques (Çamköy). They usually communicate visually with the mosque. There are also village rooms (Müsellim village) adjacent to the mosque. In interviews with the villagers, it was learned that men go to the village chamber after the evening prayer and gather there. Today's reinforced concrete village rooms are also close to the village mosques.

Fig. 7. Village rooms

The village rooms that have survived today are similar to Çamlıdere traditional houses in terms of construction system and architectural elements. They are 1 or 2 storeys. There are two types of 2 stories. In the first type, the ground floor is a barn with rooms or rooms on the upper floor. In the second type, there are rooms on both floors. The single-story village rooms are used only by the village people or people who come to the village as guests. Village rooms, similar to traditional houses in terms of construction, were built with a stack and wooden frame system. There are a few rotten examples of the original village rooms. Some village rooms have lost their original features due to unconscious durability and have been damaged. This system was built unconsciously without intervention from the system systems but without adding or removing the interior architectural elements of the space (Fig. 8.)

Fig. 8. Çamköy village room

In most rural settlements of Çamlıdere, reinforced concrete village rooms or village mansions are built with contemporary construction techniques. Reinforced concrete village rooms are generally rebuilt on the parcels of traditional village rooms that were demolished. Today, these spaces are used for mass events such as dinners, weddings, and funerals. However, today, village rooms are not only used by men but also by women. Different village rooms have been built for women and men in some villages. There are also dining hall sections in these village mansions. The sofa system continues in the interior design of the newly built village rooms. Interior arrangements are similar to traditional village rooms. In rural architecture, the demolition of the old and the reconstruction of spaces with the same function are also encountered in village rooms.

Fig. 9. Dörtkonak, Müsellim, Atça, Kargalar village rooms

The village room in Muzrupağacın village has survived to the present day in its original state. However, it is not used. In the 2-story village room, three walls of the room on the upper floor are surrounded by divans. On the other wall, there is a stove in the middle and wooden cabinets on both sides of the furnace. The divans are 20 cm high and 100 cm wide. The floor and ceiling are covered with wood. The room size on the upper floor is 480-675 cm (Fig. 10).

Fig. 10. Muzrupağacın village rooms

In the Anatolian countryside, women commonly use spaces in rural settlements, generally laundries, ovens, and fountains. Apart from these public spaces, women spend most of their time in their homes. In the study conducted in the rural settlements of Çamlıdere, no structures could be defined as private spaces specifically designated for women. There are no communal village ovens; instead, women bake their bread in the stoves located within their homes. Laundries, which are observed in other regions, are places where women spend time together, socialize, and wash their laundry. However, no such laundries were found in the settlements examined during the field study. Interviews with village women revealed they wash their laundry by the streams or at fountains.

Fountains are also used for washing clothes. In the village of Çamköy, it was mentioned that there used to be a washing stone placed in front of the fountain for this purpose, but these stones have since been removed (Fig. 11).

Fig. 11. Çamköy, Müsellim, Kuşçular village fountains

Fountains, defined as women's spaces in rural settlements, are not actively used today because all houses have water. However, one of the striking aspects of the field trip was that just as men were seen around mosques and village rooms, women were also seen at the fountain. Chats were held with women living in the village at the fountain (Fig. 12).

Fig. 12. Village fountains and women

When the past and present are compared, the body codes carried by the space change with its users, the perception of society, and the dynamics of time. In the trilogy of time, space, and humans, the images, visions, and symbols that define spaces as masculine and feminine and generalize throughout the historical process change. Differentiations are experienced (Yağçı, 2014).

5. Conclusions

Çamlıdere is one of the crucial settlements with its historical and cultural texture, located northwest of Ankara. The originality of the district is reflected not only in its natural beauty but also in the places that keep its social memory alive. These places are houses, mosques, haylofts, barns, village rooms, fountains, and other structures that convey the technical and mastery knowledge of the time. These structures have an essential place in the daily rural life of Çamlıdere.

In rural settlements, spaces are produced depending on production dynamics—public spaces where time is spent together store essential data of social memory. Just as there are spaces shaped according to gender codes regarding public space in urban life, there are also spaces that differ in rural settlements. The spaces used predominantly by women are called feminine spaces. Both men and women use these spaces. However, only men use masculine spaces. It has been determined that the masculine spaces in Çamlıdere rural area are village rooms. Village rooms were multifunctional social structures at the center of village life in the past; men gathered, discussed issues, hosted guests, and made decisions. These rooms are physical structures and carriers of social belonging and shared cultural memory. In this sense, the village rooms in Çamlıdere reflect traditional Turkish hospitality and the culture of collective life. In these rooms, folk tales were told, local games were played, worship was held, and solidarity was established among the villagers. The elderly advised the young, and information was transferred between generations. Therefore, the village rooms served as the cornerstones of education, communication, and the culture of living together. In the rural area of Çamlıdere, feminine spaces appear as houses and fountains. Women spend more time in the house, which is a private area. There is no area specific to women in the public area. Today, with the phenomenon of migration, technological changes, and the decrease in the population in rural areas, traditional houses and public buildings are rapidly disappearing. The buildings are losing their original functions. Many buildings are in disuse. The physical damage to the buildings is significant. This situation threatens cultural continuity and limits our ways of connecting with the past.

Observations made within the scope of the study revealed that the use of public spaces in rural settlements has decreased, and most of these spaces have become dysfunctional and abandoned. As a result of the continuous migration of the population to big cities, especially Ankara, traditional public structures such as fountains, village halls, laundries, and similar structures are left abandoned, and this valuable spatial heritage reflecting local knowledge and production styles is disappearing without being documented. In this context, ensuring the return of the local people to the area will contribute to the re-functioning of public spaces along with rural life and, thus, to the preservation and maintenance of these structures. To re-establish the balance between conservation and use, civil society organizations, local governments, and universities must produce concrete projects in cooperation and take the necessary steps. Preserving public spaces will ensure the continuation of not only the physical structures but also the social practices and memory related to these spaces.

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Sustainable interior design in Algeria: Blending tradition and innovation for a greener future

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Abstract. Interior design in Algeria is experiencing a transformative shift toward sustainability, aiming to harmonize aesthetic appeal with environmental responsibility. This study investigates sustainable interior design practices tailored to Algerian residential spaces, focusing on optimizing material selection, energy efficiency, and spatial organization to meet the unique cultural and climatic context of the country. The methodology involves a field analysis of residential projects in urban and rural areas, complemented by interviews with design professionals and surveys with homeowners. A comparative study of traditional and contemporary designs highlights how integrating natural and locally sourced materials, such as terracotta, stone, and wood, reduces environmental impact while maintaining cultural authenticity. Results reveal that sustainable interior design in Algeria significantly benefits from passive design strategies, such as maximizing natural ventilation, optimizing daylighting, and using thermally efficient materials to reduce energy consumption. Furthermore, incorporating modular furniture and multifunctional spaces enhances the adaptability and functionality of interiors. Challenges include limited awareness of sustainable practices among homeowners and the higher costs of eco-friendly materials. However, success stories from pilot projects demonstrate that these hurdles can be overcome through education and policy incentives. This work concludes by proposing a framework for promoting sustainable interior design in Algeria, emphasizing professional training, public awareness campaigns, and partnerships with local artisans and material suppliers. The study aims to inspire designers and policymakers to adopt practices that blend modern functionality with cultural and environmental sustainability, paving the way for a greener future in Algerian homes.

Keywords: Sustainable design; Interior architecture; Algeria; Energy efficiency; Cultural authenticity

1. Introduction

In the face of growing environmental concerns and increasing energy demands, sustainable design practices have become a priority across all sectors of construction and architecture (Edwards, B, 2005). In Algeria, where traditional architecture holds a rich cultural heritage, interior design is undergoing a subtle yet transformative shift toward greener practices (Fathy, 1986). This study explores how sustainable interior design, when rooted in Algeria's climatic and cultural specificities, can successfully merge tradition and modern innovation to create environmentally responsible and culturally authentic living spaces.

2. Context and Importance of Sustainable Interior Design in Algeria

Algeria's diverse geography—from the Mediterranean coast to the vast Sahara—has historically shaped vernacular architecture that responds intelligently to environmental constraints (Ghouma & Bellal, 2012). Traditional Algerian homes, through their thick walls, small openings, and patios, offer valuable lessons in passive design strategies (Mehal, 2020). However, rapid urbanization and globalization have introduced modern building practices that often disregard climatic adaptation, leading to increased energy consumption and environmental degradation (Baniyounes & Ghoul, 2017).

The interior design sector, particularly in residential projects, presents a significant opportunity to reintroduce sustainability at the heart of living spaces (Boutabba & Sassi, 2018). Sustainable interior design not only aims to minimize ecological footprints through responsible material use and energy efficiency but also seeks to enhance occupants' well-being by creating healthier indoor environments. In Algeria, embracing sustainability within interior spaces can serve as a bridge between preserving cultural identity and meeting contemporary needs for comfort, efficiency, and aesthetics.

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3. Methodology

This research adopts a mixed-methods approach, carefully combining qualitative and quantitative data collection to capture a comprehensive understanding of sustainable interior design practices in Algeria.

Field Analysis: Site visits were carried out across a curated selection of residential projects in both urban and rural settings. In urban areas, projects in Algiers and Constantine were analyzed, while in rural regions, the focus was on Ghardaïa and Boussaâda, two cities known for their rich vernacular traditions. The analysis involved a detailed observation of material choices, spatial organization, energy consumption patterns, and environmental performance of interiors. Data such as thermal comfort levels, daylighting quality, and natural ventilation effectiveness were systematically recorded during site assessments (see Fig. 1).

Fig.1. Geographical distribution of surveyed residential projects in Algeria

Interviews: Semi-structured interviews were conducted with a diverse group of 15 professionals, including interior designers, architects, and sustainability consultants. The interviews explored their practical experiences, challenges faced when implementing sustainable principles, and perceptions regarding the evolution of client expectations. Open-ended questions allowed interviewees to elaborate on specific projects and innovations they had applied or witnessed in the field.

Surveys: Parallel to the professional interviews, a structured questionnaire was distributed among homeowners who had either recently renovated or built their homes. A total of 82 valid responses were collected. The survey assessed perceptions of sustainability, priorities in material and design choices, willingness to invest in eco-friendly solutions, and awareness of traditional passive design strategies.

Comparative Study: A comparative analysis was undertaken to juxtapose traditional Algerian interiors with contemporary residential designs. Traditional examples included homes from the Casbah of Algiers, the M'zab Valley in Ghardaïa, and old dwellings in Boussaâda, all of which demonstrate sustainable design principles inherently embedded within cultural practices. Key features such as the use of local materials (e.g., clay, natural stone, palm wood), the optimization of natural lighting, and passive thermal regulation were examined. Contemporary designs, often characterized by modern materials and construction techniques, were assessed to identify gaps and opportunities where integrating vernacular knowledge could improve environmental performance.

To structure this comparative evaluation, a set of sustainability indicators was established, including material lifecycle impact, energy efficiency, thermal comfort, and cultural authenticity. Each interior was then scored based on these indicators to derive meaningful patterns and insights.

4. Results and Discussion

4.1 Field Analysis Results

The field analysis revealed notable differences between urban and rural residential projects regarding sustainable interior practices.

In urban homes (Algiers, Constantine), modern materials such as concrete, ceramic tiles, and synthetic paints dominated. However, some efforts were made to introduce double-glazed windows and insulated walls to improve thermal efficiency.

In rural homes (Ghardaïa, Boussaâda), traditional materials like mudbrick, stone, and lime-based plasters were still prevalent. These materials provided excellent natural insulation and thermal inertia, especially against the region's extreme temperatures.

Moreover, passive strategies such as inner courtyards, thick walls, small window openings, and orientation optimization were recurrent features in rural designs but largely absent in new urban constructions.

Table 1. Summarizes the prevalence of different materials

Material Type	Urban Projects (%)	Rural Projects (%)
Locally Sourced Stone	15%	68%
Mudbrick	3%	72%
Concrete	85%	28%
Ceramic Tiles	90%	45%
Wood (Palm/Walnut)	20%	62%

4.2 Interview Findings

The interviews highlighted several key themes:

Awareness Gap: Although professionals were generally aware of sustainable design principles, many emphasized that client's prioritized aesthetics and costs over sustainability.

Material Availability Issues:

Several designers noted difficulties in sourcing certified eco-friendly materials locally, leading to compromises in project design.

Positive Trends: Younger designers and boutique studios are increasingly experimenting with recycled materials, earth plasters, and modular furniture systems.

Quote from an Interviewee: "Clients are becoming more curious about natural materials, but when they see the cost difference compared to conventional options, many hesitate. Education is crucial." (Architect, Algiers).

Table 2. Emerging Themes from Professional Interviews

Theme	Frequency of Mention (%)	Description
Cost Concern	88%	High costs of sustainable materials limit adoption.
Material Scarcity	76%	Difficulty accessing eco-friendly, local materials.
Cultural Heritage	64%	Desire to preserve traditional design elements.
Eco-Innovation	59%	Interest in using modern green technologies creatively.
Client Awareness	52%	Clients' lack of knowledge about sustainable interiors.
Policy Support Need	48%	Lack of supportive regulations or incentives.

4.3 Survey Results

The survey conducted among homeowners yielded the following insights:

Awareness Levels: 37% of respondents reported familiarity with the concept of sustainable interior design, while 63% were unfamiliar or only vaguely aware.

Priorities in Design Choices: Homeowners primarily valued durability (87%), aesthetics (81%), and cost (76%), with environmental impact (42%) ranking lower.

Interest in Eco-Friendly Solutions: When informed about the potential energy savings and health benefits, 68% expressed willingness to consider sustainable design in future projects.

Table 3. Homeowner Priorities When Selecting Interior Materials

Priority Factor	Percentage of Respondents
Durability	87%
Aesthetic Appeal	81%
Cost	76%
Environmental Impact	42%
Cultural Authenticity	35%

4.4 Comparative Study: Traditional vs. Contemporary Designs

The comparative study revealed that traditional Algerian interiors already embody many sustainable strategies that contemporary designs could adapt and modernize.

Traditional Interiors: Use of natural ventilation (wind towers, shaded courtyards). Strategic sunlight control (small openings, thick walls). High thermal inertia (materials like adobe and stone). Minimalist furnishing reducing material consumption.

Contemporary Interiors: Often rely heavily on mechanical cooling/heating. Extensive use of imported, energy-intensive materials. Poor consideration of orientation and solar gains.

Table 4. Comparison of Sustainability Features

Feature	Traditional Interiors	Contemporary Interiors
Natural Ventilation	Strongly Present	Weak
Solar Shading	Strongly Present	Moderate
Use of Local Materials	Dominant	Rare
Energy Consumption	Low	High

4.5 Discussion

The results indicate that returning to vernacular wisdom while integrating modern technology offers the most effective pathway toward sustainable interior design in Algeria.

Passive Design Strategies inherited from traditional architecture outperform many modern systems in terms of energy efficiency.

Material selection is crucial; the use of locally sourced, natural materials reduces embodied energy and carbon emissions.

Homeowner education plays a vital role: increasing awareness significantly boosts willingness to adopt sustainable solutions.

Cost barriers remain a challenge, but emerging practices like modular design and local artisan partnerships can offer scalable, cost-effective alternatives.

The synergy between tradition and innovation can provide Algerian interiors with not only environmental benefits but also stronger cultural identity in a rapidly globalizing market.

5. Recommendations:

5.1 Integration of Local and Natural Materials

Traditional Algerian interiors extensively use materials such as terracotta, stone, palm wood, and lime-based plasters—all sourced locally and requiring minimal processing. Contemporary sustainable projects that consciously reintroduce these materials show a reduction in embodied carbon emissions and better thermal performance compared to conventional modern interiors reliant on imported synthetic materials.

5.2 Passive Design Strategies

Passive cooling and lighting techniques, observed in both traditional and modernized interiors, significantly improve energy efficiency. Techniques include:

Maximized natural ventilation through cross-breezes enabled by strategic window placement.

Daylighting optimization via central courtyards (patios) and light wells.

Thermal mass utilization to stabilize indoor temperatures despite harsh external climates.

Residences employing these strategies recorded energy savings of up to 35% in cooling needs compared to standard designs without passive elements.

5.3 Spatial Organization and Functional Adaptability

Sustainable interiors increasingly feature modular furniture, multifunctional spaces, and flexible layouts to enhance adaptability and maximize use of available space. This design philosophy echoes traditional multi-purpose rooms found in older Algerian homes, where living areas often served dual functions.

5.4 User Awareness and Material Perception

Surveys revealed a limited understanding of sustainability among homeowners. Although there is strong cultural attachment to traditional aesthetics, few participants associated traditional materials with environmental benefits. Eco-friendly materials were also perceived as costlier, discouraging broader adoption.

6. Challenges and Opportunities

Despite promising examples, the widespread adoption of sustainable interior design in Algeria faces several challenges:

Economic Barriers: Higher initial costs of eco-friendly materials and technologies.

Lack of Awareness: Limited public knowledge about the benefits of sustainable interiors.

Policy Gaps: Absence of strong regulatory incentives promoting green interior practices.

However, these challenges present corresponding opportunities:

Educational Programs: Integrating sustainability into design education can equip future professionals with essential skills.

Public Awareness Campaigns: Media initiatives can reshape public perceptions and highlight long-term cost savings.

Local Artisan Partnerships: Collaborations with local craftsmen can promote the use of traditional, sustainable materials while supporting local economies.

7. Proposed Framework for Promoting Sustainable Interior Design

Based on the findings, a multi-faceted framework is proposed to embed sustainability into Algerian interior design practices:

Professional Training: Specialized workshops and certification programs for designers and architects on sustainable materials, energy-efficient strategies, and vernacular design principles.

Policy Initiatives: Government incentives, such as subsidies or tax reductions, for projects incorporating green interior strategies.

Community Engagement: Interactive exhibitions and participatory workshops with homeowners to raise awareness about sustainable living spaces.

Strengthening the Local Supply Chain: Investing in local production of sustainable materials to lower costs and ensure accessibility.

By implementing these measures, Algeria can cultivate an interior design culture that not only respects its rich traditions but also contributes actively to global environmental goals.

8. Conclusion

Sustainable interior design offers a meaningful pathway to harmonize Algeria's cultural heritage with contemporary environmental imperatives. By intelligently integrating local materials, passive strategies, and adaptable spaces, interior environments can significantly reduce ecological impacts while enhancing quality of life. Although barriers exist, a combination of professional education, public outreach, and supportive policies can accelerate the transition toward greener interiors. As Algeria navigates its path toward sustainable development, interior spaces, where daily life unfolds, must not be overlooked. They hold immense potential to embody the values of resilience, identity, and ecological stewardship essential for a greener future.

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Shaping behavior and emotions through urban design: tackling social inequality

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Abstract. Rapid urbanization leads to major problems such as overcrowding, social fragmentation, and unequal distribution of resources in cities. Urban Design is an important tool to solve urban problems via design. In light of that, this study examined urban design approaches and their psychological impacts, exploring the role of urban design in influencing behaviors, emotions, and social equity with detailed case studies. The literature review of the study mainly focuses on urban design strategies, the psychological effects of the urban environment, the role of inclusive design, and the promotion of social cohesion. These theoretical foundations are reinforced by case studies focusing on various urban spaces implementing innovative design strategies to enhance social interaction and emotional well-being. The findings have revealed that well-designed urban spaces can foster positive behaviors, reduce stress, and improve overall emotional health. The study demonstrates a positive correlation between inclusive urban design and enhanced emotional well-being, social cohesion, and equity.

Keywords: Urban design; inclusive design; public space; social equity; emotional well-being.

1. Introduction

Urban design plays a crucial role in shaping human behavior, enhancing pedestrian safety, ensuring accessibility, and optimizing the use of public spaces. Cities around the world have adopted various urban design strategies to foster healthier, more inclusive, and socially cohesive communities.

This research paper explores the impact of urban design on human behavior and social dynamics through case studies. In recent years, urban design theories have transcended traditional boundaries, addressing not only aesthetic and functional aspects but also the social and psychological well-being of citizens. Examining case studies offers valuable insights into how design interventions can promote physical activity, reduce traffic congestion, enhance community interactions, and improve all quality of life (Gehl, 2010; Mueller et al., 2020).

This paper is structured into three primary sections, which are behavioral, social, and emotional influences of urban design. This study further investigates specific case studies elucidating how urban design can substantively influence behavior, facilitate social interaction, and enhance emotional well-being. The paper focused on defining the relationship between urban design elements and social outcomes by analyzing "the impact of urban design on people's behavior and emotion" and "the impact of urban design on the level of social inequality".

2. Literature review

Urban design is one of the important factors in shaping human experiences by influencing behavior, social interactions, and emotional well-being. Various studies have explored how spatial configurations, accessibility, and inclusivity impact social cohesion and individual perceptions of safety and belonging (Gale, 2010; Jacobs,1961). The contemporary urban design highlights the importance of creating public space and fostering community engagement, reducing social inequalities, and promoting healthier lifestyles. This chapter provides an overview of the theoretical framework and previous research related to urban design's behavioral, social, and emotional effects, setting the foundation for the case studies analyzed in the later sections.

2.1 Behavioral influence of urban design

The design of urban spaces significantly shapes individual behaviors, with open forms and spatial configuration playing a crucial role in guiding movement and interactions (Southworth,2016). People experience the city

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kinesthetically, navigating through sequences of urban spaces that influence their perception and engagement with the environment (Cullen,1971/2012).

A key factor in this experience is street layout, which directly impacts walkability, social interactions, and preferred residential and business environments. Grid patterns, characterized by numerous intersections, facilitate shorter distances and ease of navigation, encouraging walking and cycling over car use. This interconnectedness enhances social engagement by fostering stronger community ties and a sense of belonging (Frank et al., 2006). Beyond mobility, urban design also affects neighborhood security through the principle of natural surveillance. Jacobs (1961) introduced the concept of “eyes on the street,” highlighting how well-designed streets that promote visibility contribute to a watchful environment, discouraging crime. By strategically positioning physical spaces, activities, and individuals to maximize visibility, open planning can create safer, more connected communities where positive social interactions thrive.

Natural surveillance in street design is intended to improve community safety and build social bonds. Features like low shrubs, street lights, pedestrian-friendly sidewalks, and transparent fences create a safety- and invitation-oriented environment. That encourages citizens to expose themselves to their environment, community, and well-being (Jacobs, 1961). Additionally, the design of public places is a crucial consideration in urban environments. Well-designed public spaces create a sense of community by providing for socializing. These public spaces, such as parks, plazas, and recreational areas, all citizens must be found safe and inviting (Gehl, 2010; Whyte, 1980). Public space design that focuses on more inclusive and accessible approaches ensures that citizens, regardless of social status, benefit from public spaces. These principles contribute to efficient and well-being urban environments, creating favorable conditions for social equity and social cohesion (Gehl, 2010; Whyte, 1980; Talen, 2000). Designed urban spaces significantly shape individual and collective behaviors by influencing movement patterns, social interactions, and perceptions of security. Walkable neighborhoods with interconnected streets encourage activities, mobility, spontaneous social engagement, and a stronger sense of community belonging. This behavioral shift can reduce automobile dependency, promoting environmentally sustainable habits and healthier lifestyles.

2.2 Social influence of urban design

Inclusive urban design plays a crucial role in fostering community engagement by creating well-designed spaces that encourage social interactions (Gehl, 2010). Mixed-use developments, which integrate residential, commercial, and recreational areas, contribute to social integration by promoting diverse interactions among citizens (Whyte, 1980). Providing spatial justice in urban design with the notions of accessibility, sociability, and diversity is possible, particularly concerning public open spaces (POS), by addressing their inherent complexity (Jian et al., 2020).

Walkability, affordability, and safety are key variables in assessing the inclusivity and accessibility of urban environments (Gehl, 2010). Within this framework, sociability and diversity represent the ability of POS to facilitate meaningful social interactions, contributing to stronger community bonds (Whyte, 1980). Furthermore, factors such as activity support play a vital role in enhancing engagement within public spaces (Gehl, 2010; Whyte, 1980). However, despite the access to POS, he highlights socioeconomic differences among various groups, reflecting border issues of equity and inclusion in urban planning (Jiang et al., 2020). Evaluating these disparities provides insights into how effectively POS can create inclusivity for diverse users (Talen, 2000). By prioritizing accessibility, safety, and social integration, urban design can foster cohesive communities and equitable public spaces.

On the other side, other justice-related studies stated that spatial justice emerged quite late and is still an undefined concept (Pereira et al., 2017). Earlier, researchers used to mention the terms "territory justice" (Harvey, 1973) or "social justice in space" (Pirie, 1983) to elaborate their research interests and spill their focus on spatial perspective. The theoretical foundations of this have led some scholars to mark a distinction between spatial justice as opposed to the general view of justice. Among different kinds of spatial injustice, two crucial forms, the involuntary clustering of a particular group into a confined space (as segregation) and the allocation of resources unfairly, are identified (Marcuse, 2009, p. 1).

Meanwhile, Lefebvre's concept of "the right to the city" has reached many urban researchers, and they have started to rethink justice from distributional rights to the right to participation in the making of the city (Fainstein, 2014). Soja's (2010) theory echoes in that argument. The author elaborates spatial justice through a triangular framework made up of three components, namely physical justice, urbanization of social justice, and right to the city that centered his critiques of injustice on the locational bias, the political organization of space, and the inequality in distributional outcomes that overlooked the production process (Iveson, 2011).

Well planned public spaces encourage social engagement by creating environments that support accessibility and inclusivity reinforcing trust and positive interactions within the community however disparities in access to public spaces highlight awarded issue of equity as some groups may face limitations due to locations or socioeconomic factors thoughtful urban design must balance accessibility and community engagement promoting social cohesion and overall wellbeing.

2.3 Emotional influence of urban design

The integration of green spaces and aesthetically pleasing environments in urban design significantly enhances mental and physical health. Biophilic designs, which emphasize incorporating natural elements into built environments, increase interaction and overall life satisfaction (Mitchell & Popham, 2008). These designs create spaces where people can connect with nature, fostering a sense of wellbeing and belonging among city inhabitants. Access to natural environments plays a crucial role in stress reduction and promoting relaxation. Ulrich (1984) found that exposure to natural settings, such as infant parks, can reduce stress levels and contribute to emotional well-being.

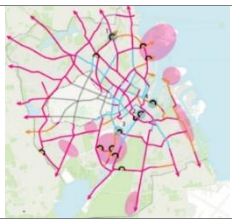
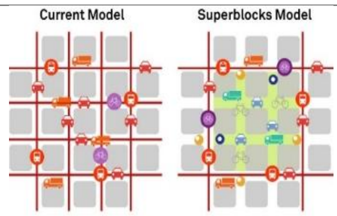
Culturally significant landmarks, appealing architecture, and design evoke feelings of pride and a sense of place. Appealing public spaces and aesthetically pleasing environments create positive emotions and contribute to the quality of life. Designing public spaces that are inviting, accessible, and conducive to social interactions, and these spaces for citizens of the community enhance the emotional and psychological well-being of the citizens. The integration of green spaces, natural environments, culturally significant landmarks, and urban design significantly improves well-being and reduces stress (Gehl, 2010). By prioritizing these elements, designers can create environments that promote social cohesion, cultural identity, and overall satisfaction (Mitchell & Popham, 2008; Ulrich, 1984; Gehl, 2010). Mental and physical health are factors to consider when designing spaces that enable people to connect with nature, as this connection can significantly enhance their emotional and physical well-being while also promoting stress reduction.

3. Case studies

Case studies from Copenhagen, Portland, and Barcelona illustrate how different cities have effectively utilized urban design strategies to enhance human behavior, promote pedestrian safety, improve accessibility, and optimize the use of public spaces to address social inequality.

Each case study presents a unique approach that offers a diverse range of insights. For instance, Copenhagen employs a network of interconnected bike lanes and pedestrian streets, while Portland adopts a grid street layout. In Barcelona, the implementation of "Superblocks" transforms streets into public spaces through these distinct urban design strategies. Each city focuses on improving accessibility, pedestrian safety, and equitable use of public spaces, making significant strides in addressing social inequality through thoughtful spatial planning. The behavioral, social, and emotional impacts of urban design were analyzed through the selected case studies presented below.

Table1. Behavioral Influence

			
Name location	Copenhagen, Denmark (2010)	Portland, Oregon, USA (2009)	Barcelona, Spain (2006)
Features	Interconnected bike lanes, pedestrian streets.	Grid street layout.	"Superblocks" concept, restricted traffic, repurposed streets as public spaces.
Outcomes	High physical activity, reduced traffic congestion, and enhanced community interaction.	Promoted sustainable living, reduced car dependency, and vibrant local communities.	Reduced traffic accidents, noise pollution, air pollution, and more social interaction areas.
Effects on behavior and security	Increased daily exercise, greater social cohesion, healthier lifestyle choices Improved pedestrian crossings.	Increased local shopping, more community engagement, greater sense of belonging Community policing, safe routes for walking and biking.	Reduced car speeds, surveillance cameras for safety in outdoor activities, and stronger community ties.
References	Gehl, J. (2010). Cities for People.	Portland Plan, City of Portland (2009).	Mueller, N., et al. (2020). Changing the urban design of cities for health: The superblock.

As shown in Table 1, Copenhagen, Portland, and Barcelona are cases of how urban design can affect people's actions and address social inequality. In Denmark, the 'Five-Finger Plan' integrates cycle lanes with pedestrian ways to create a space for active lifestyles and improve connectivity between neighbourhoods. Such a design can allow citizens from differing socio-economic backgrounds to engage in activities that promote health and create a culture of cycling and walking. Improved pedestrian crossings and traffic calming measures further ensure that even those in lower-income areas can navigate the city's streets safely, promoting inclusivity and encouraging them to participate in community life (Gehl, 2010). More green spaces equate to more livability for Copenhagen, further creating environments where people can be outside and engage in physical activities.

Parks and public squares act as places for collective gatherings where socializing and community events happen, creating a sense of belonging and shared identity for the citizens. They also act as an escape from urbanity, providing space for comfort and mental refreshment (Gehl, 2010). In Portland, with local street layout and the '20-minute neighborhood' concept, access to basic services for the citizens of different income levels is assured. This scenario, therefore, minimizes the car travel expense that is most burdensome for low-income households and helps invigorate local communities.

The urban design of Portland encourages healthy options: walking to shop in the neighborhood. It intervenes across economic lines, fostering a place to become increasingly vibrant with community participation, in turn, generating a feeling of belonging (City of Portland, 2009). Essentially, the city of Portland has thrown more weight upon the design and construction of walkable neighborhoods and well-connected public transportation systems. This has led to a more equitable city in which the neighborhood citizens have easy access to schools, workplaces, and recreational areas. Such neighborhoods include community centers, farmers' markets, and local businesses to strengthen the social fabric and invigorate the local economy. Finally, they straightaway bring down the need for long distance commuting and reduce car dependency, promoting environmental sustainability and enhancement of quality of life for Portland's city dwellers (Talen, 2012)

Spain's "superblocks," which are exclusively pedestrian and bicycle-accessible, are one of the frontier representative examples of creating inclusive urban environments. The affordances include minimal noise and air pollution, thereby improving the environment of all citizens-pore to pore comparisons between the most oppressed and well-established create socially cohesive spaces for interaction, recreation, and activity for different groups (Mueller et al., 2020). Success, such as that which cities like Barcelona enjoy with superblocks, demonstrates that people can be prioritized over cars by careful design in urban settings, thereby transforming the ecosystem into one that supports health and wellness. Such street configurations are made to serve as public spaces, where children can play in safety, seniors walk without risk, and neighbors gather for social interaction. Superblocks' addition of greenery and recreational facilities creates a sense of lifetime community and motivates citizens to live an active and healthy life (Gehl, 2010). While these urban strategies foster social inclusion and well-being, their effectiveness depends on continuous adaptation to demographic shifts, infrastructure demands, and evolving community needs.

Table 2. Social Influence

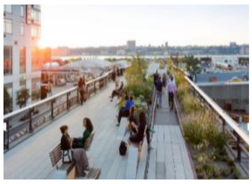
			
Name location	Bryant Park, New York City (1947) redeveloped in (1988)	Federation Square, Melbourne (2002)	The High Line, New York City (2009)
Features	Open lawn for events, outdoor seating, including various movable seating options.	The central plaza for public events and performances, cafes and restaurants for social interactions, and the square hosts cultural and community events.	"The park features art installations, diverse programs, an elevated greenway besides interactive programs, guided tours, and educational events.
Outcomes	Improved public perception of safety, highlighting the vibrant parks, can deter criminal activity by increasing pedestrian presence and fostering collective community ownership.	Transformed Federation Square into a central hub for social and cultural activities, enhancing urban vibrancy.	Transformed an industrial space into a vibrant public park, creating biodiversity and attracting millions of visitors.
Social influence	Encourage daily social interactions, assemble a community, and provide a simple and accessible environment for all ages.	Enhances open social life and promotes inclusivity and accessibility by fostering public interactions through diverse cultural events.	Encourages walking and interaction along its path, creating unique surface spaces within an open setting and enhancing community engagement through art and nature.
References	Urban Land Institute [ULI], Padua et al., 2022; Goldberger, 1992.	Lu, 2022; Bates & Davidson, 1997	Aitani, 2017; Soria, 2016

Table 2 highlights how urban design significantly influences social interactions and community participation in various locations, including Bryant Park in New York City, Federation Square in Melbourne, and the High Line, also in New York City. Bryant Park, with its open lawns, outdoor seating, and seasonal events, serves as a vibrant hub for social activity and has fostered increased public participation, reclaiming space in the urban environment.

These design features encourage daily social interactions, creating community spaces that are accessible and safe for people of all ages, from infants to the elderly (Kaufman, 2016; Padua et al., 2022). In contrast, Federation Square, which includes a public plaza, cafes, and public art, is essential to the cultural and social fabric of the city. It contributes to urban vibrancy and tourism, fostering a sense of pride within the community by activating social and cultural experiences. By hosting a variety of cultural and social events in its popular spaces, it facilitates gatherings for both visitors and citizens alike (Lu, 2022; Bates & Davidson, 1997).

The High Line, an elevated linear park, transforms an industrial space into a lively social artery, featuring a diverse array of plantings, walking paths, and art installations. This unique design encourages social interactions along its route, creating distinct social spaces within the urban setting. It enhances community engagement through art and nature, and economic activity, contributing to social change alongside increases in green space and biodiversity (Aitani, 2017; Soria, 2016). These urban spaces effectively shaped behaviors by fostering inclusive interactions, cultural engagement, and a shared sense of belonging, demonstrating how design can transform public participation and community cohesion.

Table 3. Emotional Influence

			
Name location	Central Park, New York City (1858) designed, major restorations in (1934 & 1980s)	Cambridge Road Community Resilience Project, Singapore (2018)	Punggol Waterway Park, Singapore (2011)
Features	The design mimics natural landscapes with rolling meadows, tranquil lakes, and wooded areas, integrating diverse plant species and creating both active and reflective spaces.	Central plaza for public events and performances, cafes and restaurants for social interactions. The square hosts cultural and community events.	Human-made waterway integrated with recreational facilities, landscaped parks, and green corridors; designed for both active and passive recreation.
Outcomes	The park serves as a natural sanctuary, with a network of trails, sports fields, and recreational areas that encourage physical activity, contributing to lower obesity rates and improved cardiovascular health among citizens.	Community-led climate action plan, green corridors, and improved public infrastructure.	Transformed an industrial space into a vibrant public park, creating biodiversity and attracting millions of visitors.
Emotional Influence	Reduces stress, anxiety, and mental fatigue; promotes relaxation and mental rejuvenation; allows people to feel close to nature amidst urban density.	Reduces stress by providing cooler, shaded areas; fosters a sense of belonging and community support through collaborative efforts.	Enhances emotional well-being through access to nature, leisure activities, and scenic views; reduces stress and promotes relaxation.
References	Ulrich, 1984; The Central Park Conservancy, 2024.	Chengyan et al., 2024.	Huang & Lin, 2017.

As shown in Table 3, New York City's Central Park possesses an intriguing characteristic, its features include green areas and diverse, well-planned landscapes that mimic various natural environments, even in heavily populated urban settings. This provides a respite from the hustle and bustle of city life, reducing mental strain and allowing individuals to reconnect with nature (Ulrich, 1984; Kaufman, 2016; Padua et al., 2022).

The Cambridge Road Community Resilience Project in Singapore stands out due to its community action approach and the creation of green corridors and shaded pedestrian walkways that contribute to a cooler, less stressful environment. These initiatives create a sense of belonging and enhance community support through collaborative efforts, significantly increase social resilience and inclusivity (Chengyan et al., 2024; Centre for Liveable Cities, 2018).

Punggol Waterway Park is unique in Singapore for integrating an artificial waterway with recreational facilities and landscape parks designed for both active and passive recreation. This city park enhances the general public's emotional well-being by promoting connections with nature, offering leisure activities, and providing good views. It also nurtures social networks and community involvement by linking various residential areas (Huang & Lin, 2017). Together, these examples illustrate the potential of well-thought-out and systematic urban strategies to enhance emotional well-being and strengthen community ties.

4. Conclusion and Discussions

This study has highlighted the critical role that urban design plays in shaping human behavior, social interactions, and emotional well-being.

The evaluation of case studies from cities like Copenhagen, Portland, and Barcelona, as well as various urban settings, reveals that inclusive urban design can significantly boost accessibility, safety, and social equity. For instance, the impact of urban design on behavior was particularly visible in pedestrian-friendly streets and cycling networks, which promoted healthier lifestyle choices. Similarly, vibrant public spaces were shown to strengthen community connections and ensure equitable access for all citizens. Moreover, emotional benefits were noted in designs that incorporated green spaces, calming landscapes, and cultural landmarks, which contributed to enhancing well-being and fostering a deeper connection to urban environments.

Overall, the findings underline that well-designed urban spaces not only encourage physical activity but also help reduce traffic congestion, enhance social engagement, and elevate the overall quality of life. Additionally, environments rich in natural elements play a significant role in reducing stress and improving emotional resilience among city citizens.

This paper contributes to existing literature by offering insights into the evolving role of urban design. From an interdisciplinary perspective, a link between urban design and behavioral studies was explored to provide an equitable city development approach by comparing multiple case studies.

This research extends discussions on urban intervention strategies that prioritize human-centered design, the exploration of social equity further aligns with the concept of right to the city, advocating for urban spaces that cater to diverse socioeconomic groups, besides highlighting the need for continuous adaptation of urban environments. Cities that accommodate shifting demographics and developments should prioritize inclusive public spaces to ensure accessibility for all citizens and encourage sustainable mobility by integrating cycling and pedestrian infrastructure, which fosters social interactions while reducing congestion additionally strengthening community participation.

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Sustainable landscape planning in Muradiye Külliyesi historical area

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Abstract. Bursa, one of the earliest capitals of the Ottoman Empire, is home to many historical buildings that reflect Islamic civilization and architectural tradition which are still observable in the city center. One prominent historical site is the Muradiye Külliyesi area, which includes mosques, madrasas, bathhouses, public kitchens, and 12 tombs. The surrounding neighborhood also boasts several museums and historical sites, such as the Şair Ahmet Paşa Medresesi, Uluumay Osmanlı Halk Kıyafetleri ve Takıları Museum, Osmanlı Ev Museum, Hüsnü Züber House, Romangal İpek Fabrikası, and Hamza Bey Külliyesi. These historical buildings are located in Osmangazi, Bursa's most populous district. The district has a variety of improvement areas in and beyond its historical core where revitalization could lead to changes in infrastructure, technology, and lifestyle, positively influencing how the historic buildings are preserved and managed. This research focuses on identifying the landscape elements in the Muradiye Külliyesi area, assessing the quality of the historical landscape, and developing strategies for sustainable landscape planning in urban historic areas. This is expected to provide sustainable benefits while minimizing the possibility of negative social, economic and environmental impacts. The research methods include landscape element analysis, historical landscape quality assesment, and spatial analysis. The potential of historic building elements was included in the quality of historical landscape assesment showed a high value. Spatial analysis divides the area into three zones: Tourist Active Zone, Local Community Zone, and Buffer Zone.

Keywords: historical buildings; landscape quality; spatial analysis; landscape planning; sustainability

1. Introduction

In the multifaceted and complex field of urban planning, sustainable development is an indispensable element. The concept of sustainable development refers to efforts to meet the needs of the present without compromising the ability of future generations. The same concept also applies to the sustainability of historic areas, which play an important role in maintaining the history and development of a city. In the context of sustainability, sustainable landscape planning is evolving as an approach that emphasizes the importance of balance between ecological integrity, social needs, and aesthetic values. This approach encourages landscape design and management that not only considers ecological functions, but also responds to human interests and creates visually interesting environments. In other words, the main strength of sustainable landscape planning is the ability to create harmonious and resilient landscapes that provide long-term benefits for both people and the environment (Bariş & Kaygusiz, 2023).

Bursa as the capital of the Ottoman Empire, which became the political and cultural center of the time, holds historical value for the development of cities in Türkiye. In the aftermath of the conquest of Bursa, there have been multiple periods of building efforts and repairs which ensured that many structures from those periods survive to the present day. Afterwards, additional development also took place in the late 19th century which contributed to the cityspace, especially in the city center. Bursa is the cradle of important cultures. In Bursa, which is a transition zone between East and West, we see traces of Hittite, Phrygian, Lydian, Roman, Byzantine, Seljuk and Ottoman cultures. Thus, Bursa has an important place in the history of Türkiye with its geographical location, historical heritage and as the home of earliest capital of the Ottoman Empire.

Bursa, an important city during the Turkish history, has a rich Ottoman cultural heritage such as mosques, complexes and traditional markets. One of these historical buildings is the Muradiye Külliyesi area, which was the last külliye built in Bursa. Muradiye Külliyesi is home to a number of mausoleums in the Turkish-Islamic world with 12 mausoleums in addition to mosques, baths, madrasas and tombs. There are also many historical buildings around the Müradiye Külliyesi. Some of these historical buildings are the Şair Ahmet Paşa Madrasa, Uluumay

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Osmanlı Halk Kıyafetleri ve Takıları Museum, Osmanlı Ev Museum, Hüsnü Züber House, Romangal İpek Fabrikası and Hamza Bey Külliyesi (Elbas, 2011).

The existence of Müradiye Külliyesi in Osmangazi, the most populous district of Bursa, may change the way people perceive historical heritage. Urban centers that are closely related to revitalization can cause changes in infrastructure, technology, and lifestyle, which can affect the way historic buildings are evaluated and managed. In general, urban revitalization and urban conservation projects have been supported by the European Union for projects focused on improving sustainability, culture, tourism, and urban image in recent years. Urban revitalization is the overall actions taken to bring a more dynamic economic, social and cultural position from the existing situation of a certain region of the city (Büyük, 2019).

This research aims to identify and understand the historic buildings within the Müradiye Complex. By recognizing these historic structures, we can assess and understand the spatial characteristics of urban areas with historical value. This knowledge allows for more precise planning to ensure the preservation and sustainability of these areas, keeping their identity and historical heritage in line with the city's development.

2. Methods

2.1. Location

This study is located in Osmangazi, Bursa City, Türkiye (Fig. 1). This location was chosen based on the consideration that there are historical building sites such as Muradiye Külliyesi (Muradiye Complex), Şair Ahmet Paşa Medresesi, Uluumay Osmanlı Halk Kıyafetleri ve Takıları Museum, Osmanlı Ev Museum, Hüsnü Züber House, Romangal İpek Fabrikası, and Hamza Bey Külliyesi (Hamza Bey Complex).

Fig. 1. (a) Bursa City; (b) historical object in Muradiye Külliyesi
Source: Wikimedia Commons contributors and map digitation from Google Earth, © Google, Inc.

2.2. Data Collection

The data was collected by: (1) observations on the elements of the historic landscape; (2) reviewing previous research and local government online reports related to the study area; and (3) observations on the management of historic buildings.

2.3. Data Analysis

2.3.1. Historical Landscape Image Element Analysis

The analysis of historical landscape image elements was adopted from the concept of the city image and its elements by Kevin Lynch (1964) (Lynch, 1964), which analyzed the effects of physical objects that can be seen based on social, functional, or historical meanings. The image of the landscape can be seen in terms of physical form, which is classified into five types of elements;

(1) Path are the pathways or routes that observers use to move around the city. These can be roads, public sidewalks, transit lines, rivers, railway lines or frequently used pedestrian routes;

(2) Edge is a linear element that acts as a boundary between two specific areas, although it is not always used as a road. For example, it can be a beach, a wall or the boundary between an urban area and an open space such as a railway;

(3) District is an area within a city that shares similar characteristics in shape, pattern and form. Districts or areas have clear boundaries and are often recognized as distinct areas within the city. Districts can be seen as an internal or external reference. Districts have a better identity if their boundaries are clearly defined and their functions are clear;

(4) Nodes are points or areas where directions or activities converge and can be changed to other directions or activities. For example, traffic intersections, train stations, airports, bridges or places where people feel they are in the center of the city; and
(5) Landmarks are visual elements that attract attention within the city, even if people cannot enter them. They serve as easily recognizable reference points and help observers navigate the city. For example, tall buildings, towers, mountains or striking historical buildings.

2.3.2. Landscape Quality Assessment

The landscape analysis of this historical area was conducted using the assessment method of authenticity and uniqueness based on Harris and Dines (1988), significance (Supriadi, 2010), and comfort aspects. The result of this process is to identify the character of each historical landscape and the values contained in the landscape (Surur et al., 2016).

Table 1. Quality Assessment Criteria of Historical Landscape (Rizki Mulya et al., 2016)

No	Criteria	Value		
		Low (1)	Moderate (2)	High (3)
Authenticity				
1	Land use	>50% changing	25-50% changing	<25% changing
2	Building	There are structure and element changing in the building. Does not show the classic style. Only have one element >50 years	There are structure and element changing in the building but show classic style. There are 2-5 historical elements >50 years	There are not structure and element changing in the building and show classic style. There are >5 historical elements >50 years
3	Circulation	There are addition of road and character changing	There are additions of road but the character not changin	There is not addition of road and the character not changing
Uniqueness				
1	Historical association	Landscape/element has not historical association	Landscape/element has low historical association.	Landscape/element has strong historical association
2	Integrity	Historical landscape element scattered in small amounts and not harmonious	Historical landscape element scattered in moderate amounts and harmonious	Historical landscape element scattered in large amounts and very harmonious
3	Different diversity	Landscape only has one historical element	Landscape has 2-5 historical elements	Lanscape has >5 historical elements
4	Aesthetic value	Landscape element has not distinctive style	Landscape element has distinctive style	Landscape element and detail of ornament has distinctive style
Significance				
1	History	Historical resource not scarce and not memorable by most society	Not the only one but scarce, not too old, and memorable by most society	Only one, scarce, very old, and memorable by most society
2	Science	There is not important value of science in landscape or object	There is important value of science in landscape or object, not the only one but scarce	There is important value of science, scarce, and only one
3	Culture	Cultural resource not abundant and not old	Cultural resource not the only one but abundant, but not too old	Cultural resource abundant, the only one, and very old

Table 1 continued

No	Criteria	Value		
		Low (1)	Moderate (2)	High (3)
Comfortness				
1	Clean from rubbish	Each 1 meter on landscape there are rubbish or there many rubbish in the core object	Each 5 meter on landscape there are rubbish or there some rubbish in the core object	There isn't rubbish on landscape and also in the core object
2	Clean from vandalism	There are >30% vandalism on landscape or there are vandalisms in core object	There are <30% vandalism on landscape but there is not vandalism in core object there are vandalism in core object	There is not vandalism on landscape and also in the core object

2.3.3. Spatial Analysis

Spatial analysis was carried out by mapping the distribution of zones from the results of the spatial identity assessment in historic urban areas in the context of sustainable development. The division of functional areas was grouped according to user groups such as tourists and residents (Zhu, 2021)

- Tourist Active Zone (TAZ): is the area with the highest concentration of tourist activities. It is the core formed by a cluster of tourism services, facilities and attractions. This sub-region not only needs concentrated tourism businesses to reduce costs or improve the efficiency of operations, but also fully develops services and businesses to make the area maximally attractive to consumers of the tourism area.
- Local Community Zone (LCZ): A concentrated area for the local community with a large number of dwellings. The main objectives of this zone are to create a safe, healthy and stable community environment, to promote the protection of existing residential areas from encroachment of excessive tourism development. This zone should be regenerated in line with the principles of guaranteeing the well-being and benefits of residents, providing daily services and facilities, reducing chaos and interference from tourists' activities, and conditionally restricting the expansion of tourism.
- Buffer Zone (BZ): It is a natural area that serves to separate the resident and tourist zones, while at the same time providing an immediate setting for a certain adjustment and further development of the above two zones.

3. Result and Discussion

3.1 Historical Landscape Elements

The historical evidence of Bursa as the political and cultural center of the Ottoman Empire can be seen in the historical buildings and museums that can be found nowadays. The historic buildings in the Muradiye Külliyesi area form a unique integration and can be easily accessed due to their close location. The historical elements that can be identified in this area are not only Muradiye Külliyesi but also historical buildings and several museums that can be found around it.

3.1. 1 Muradiye Külliyesi (Muradiye Complex)

The Muradiye complex containing twelve tombs (türbe) was constructed according to the instructions of Sultan Murad II after the completion of the Yeşil Mosque in Bursa. In this area, apart from tombs, there are also mosque, madrassas, bathhouses and public kitchens. The complex underwent a major restoration after the earthquake of 1855 that damaged most of the buildings. The restoration proceeded in stages: the first period from 1855 to 1967, the second period from 1947 to 1962, and lastly from 2012 to 2015 (Tupal Yeke, 2024).

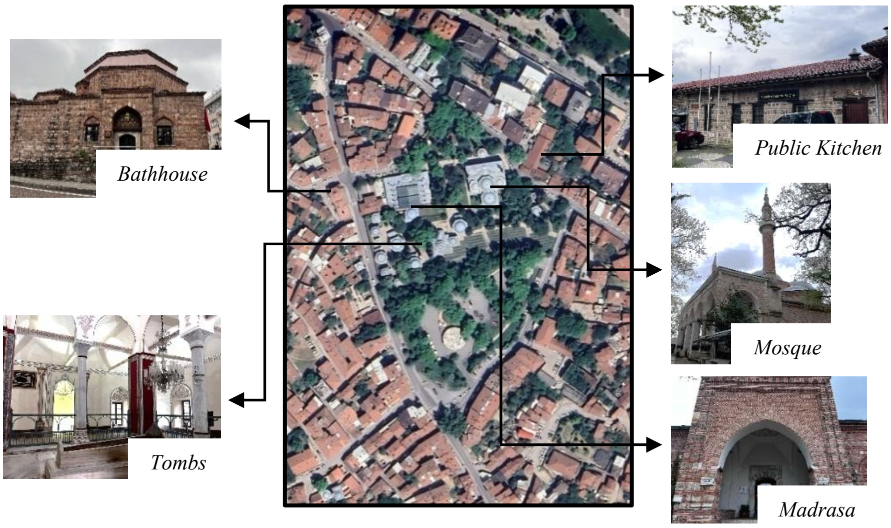

Fig. 2. Muradiye Külliyesi

3.1. 2 Şair Ahmet Paşa Medresesi

Ahmet Pasha Sultan II, a famous poet and statesman during the reign of Fatih Sultan Mehmed, was the son of Kazasker Murad, Veliyüddin Efendi. His tomb is located to the east of the madrasa he built, known as the Geyikli Madrasa. The madrasa was built in the 15th century and has been used for various purposes since then. After a restoration in 1967, it became the Muradiye General Education Center (Bursa Turizm Portalı, 2021).

The madrasa has a rectangular design with classrooms covered by a single dome, a portico with pointed arches, mirrored vaults, and eleven cells that each have a fireplace and small windows. These cells face the courtyard and are equipped with doors for natural lighting. Şair Ahmet Paşa, the founder of the madrasa, was a friend, teacher and vizier of Sultan Mehmed during the conquest of Istanbul, and left an important heritage in Muradye in the form of this madrasa (Türkiye Kültür Portalı, 2021).

Fig. 3. Şair Ahmet Paşa Tomb

3.1. 3 Uluumay Osmanlı Halk Kıyafetleri ve Takıları Museum

The museum is located inside the Şair Ahmet Paşa Madrasa and was opened on September 18, 2004. The museum exhibits a collection that Esat Uluumay, one of the founders of the Anatolian Folklore Foundation, collected over 45 years. The collection includes 70 sets of traditional clothing as well as more than 400 pieces of jewelry from Anatolia, Ottoman and Rumelia which originated in the 15th century. Other artifacts include Turkish coffee-making equipment, Ottoman bathing equipment, horse breeding equipment, as well as guns, knives and swords. The museum also contains an Ottoman Tea Garden, which provides a unique and enriching experience for visitors (Elbas, 2011).

Fig. 4. Uluumay Osmanlı Halk Kıyafetleri ve Takıları Museum

3.1. 4 Osmanlı Ev Museum

The museum is located about 100 meters from Muradiye Külliyesi and features 17th-century Ottoman history. Structurally the building has two floors, made of wood which represents the civil architecture of traditional Ottoman construction. The building has been restored and repaired several times until it was permanently opened in 2023 until now. The museum displays several examples of traditional Bursa houses, the uses of each room of the house, several examples of door styles, as well as Ottoman culture of dressing and the culture of coffee drinking in the 17th century.

Fig. 5. Osmanlı Ev Museum

3.1. 5 Hüsnü Züber House

After restoring a historic Ottoman-era house in the Muradiye District, Hüsnü Züber opened it as a "Living Museum" on December 27, 1992. On the first floor of his two-story house, visitors can find spoons and various wooden objects carved with Turkish motifs using a beautiful etching technique. There are also graphic works by Hüsnü Züber and important documents. Meanwhile, on the second floor, the living room, bedroom and main room house ethnographic collections and antiques used in daily life, providing an in-depth look into the culture and history of the past (Türkiye Kültür Portalı, 2021b).

Fig. 6. Hüsnü Züber House

3.1. 6 Romangal İpek Fabrikası

This weaving factory was built in the 19th century. First owned by Madame Brotte, it later passed into the hands of Monsieur Romangal, a Frenchman of Jewish descent. The Romangal family lived in the house facing Kaplıca Street within the factory complex until 1938. The building also served as the French Consulate for some time. In 1938, Monsieur Romangal sold the silk factory to Faik Yılmazipek, the father of Turgut Yılmazipek, who continued silk production here. The building consists of three floors with a wooden frame structure and brick walls, while the roof is covered with wooden tiles. In the factory area there are eight buildings surrounded by high walls. Most of these buildings were used as workshops for silk production and agricultural activities (Elbas, 2011).

Fig. 7. Romangal İpek Fabrikası

3.1. 7 Hamza Bey Külliyesi (Hamza Bey Complex)

The complex was originally composed of a mosque, madrasa, charity house and tombs, but only the mosque and three tombs still exist today. This mosque, the largest in Bursa at the time of Fatih Sultan Mehmed, is the main part of the Hamzabey Complex built by Hamza Bey. The building is categorized as a Zawiyali mosque, with main prayer rooms, gathering places, and guest houses on both sides. The mosque has a minaret with a single balcony, and in the complex are three tombs belonging to Hamza Bey in the northwest corner of the mosque courtyard, his wife and daughter are to the west of the mosque, while Kara Mustafa Pasha's tomb, built by his grandson, holds five coffins (Elbas, 2011) (Bursa Kültür Portalı, 2021).

Fig. 8. Hamza Bey Tomb and Mosque

3.2 Landscape Quality Assessment

The character of each historical landscape in Muradiye Külliyesi Area and its values can be seen in the area landscape assessment for each site.

Tabel 2. Landscape Assessment Results

No	Criteria	Muradiye Külliyesi (Muradiye Complex)			Şair Ahmet Paşa Medresesi			Uluumay Osmanlı Halk Kıyafetleri ve Takıları Museum			Osmanlı Ev Museum			Hüsnü Züber House			Romangal İpek Fabrikası			Hamza Bey Külliyesi (Hamza Bey Complex)		
Landscape Assessment		L (1)	M (2)	H (3)	L (1)	M (2)	H (3)	L (1)	M (2)	H (3)	L (1)	M (2)	H (3)	L (1)	M (2)	H (3)	L (1)	M (2)	H (3)	L (1)	M (2)	H (3)
	Authencity																					
1	Land use			√			√			√			√			√			√			√
2	Building		√			√			√			√			√			√			√	
3	Circulation			√			√			√			√			√			√			√
	Uniqueness																					
1	Historical assciation			√			√			√			√		√			√				√
2	Integrity			√			√			√			√			√			√			√
3	Different diversity		√			√			√		√			√				√			√	
4	Aesthetic value			√		√			√				√		√			√				√
	Significant																					
1	History			√		√			√			√			√			√			√	
2	Science			√		√			√			√			√			√			√	
3	Culture			√		√			√			√			√			√			√	
	Comfort																					
1	Clean from rubbish			√			√			√			√			√			√			√
2	Clean from vandalism			√			√			√			√			√		√				√
	TOTAL	**34**			**30**			**30**			**30**			**28**			**28**			**31**		

Based on the results of the landscape quality assessment in the Muradiye Külliyesi area, the core zone can be divided into two: the first core zone, Muradiye Külliyesi, includes mosques, tombs, bathhouses, public kitchens and madrasas with a total landscape value of 34, while the second core zone is Hamzah Bey Külliyesi with a value of 31.

3.3 Landscape Planning Concept

3.3.1. Image of Muradiye Külliyesi Historic Area

(1) *Path*

The Muradiye Külliyesi area has several paths that are routes or connecting between landscape elements. In this regard, three degrees of hierarchy can be identified for the paths. The first degree path is the one that connects the first core zone, Muradiye Külliyesi with the supporting zones, which are Osmanli Ev Museum, Şair Ahmet Paşa Madrasa and Uluumay Osmanlı Halk Kıyafetleri ve Takıları Museum. The second degree is the path connecting Hamzah Bey Külliyesi with other landscape elements that runs straight through Muradiye Külliyesi, Hüznü Züber House until Romanggal İpek Fabrikası. The third one is a pathway that connects landscape elements with local community settlements.

(2) *Edge*

The boundaries of the Muradiye Külliyesi area were determined based on the physical elements present in the area by taking the outline of the road that naturally divides the study area from its surroundings based on differences in spatial characteristics and functions. In the north, the boundary is formed by the road that separates the Muradiye Külliyesi area from the green area of Bursa Millet Bahçesi, which has a public recreation function and open space characteristics. Meanwhile, in the south, the boundary is marked by the road that separates the research area from the hillside area, which has higher contours and different ecological functions than the core area of Muradiye Külliyesi.

(3) *District*

The district in this area can be classified as a spatial unit that has a strong visual identity and characteristics, making it easily recognizable as a distinct identity from the surrounding area. This district is Muradiye Külliyesi, which is the core of the area's landscape elements. Muradiye Külliyesi takes a central position in the spatial layout of the area, surrounded by various supporting elements that strengthen its role as a visual and spatial orientation center. The presence of green open space in the form of a park located at the back of this complex serves as a buffer while emphasizing the image of the area, thus increasing the legibility and imageability of the area in the context of landscape perception.

(4) *Nodes*

The intersection at Muradiye Külliyesi plays an important role in the spatial structure of the area and can be categorized as a node in the area's movement system. This point is the center of concentration of mobility for both vehicles and pedestrians, connecting Muradiye Külliyesi with other landscape elements such as green open spaces, residential areas, and historical landscape elements in the surrounding area. The intersection not only serves as a movement route, but also helps users understand direction and position and effectively connects different parts of the area.

(5) *Landmarks*

The landmark of the area is Muradiye Camii, a historic building that is easily recognizable due to its distinctive architectural form that is different from other elements. Although not in an open area, the minaret of the mosque makes it stand out and the mosque is also surrounded by other historic buildings and elements that have a strong visual and aesthetic integrity. The presence of Muradiye Camii in the middle of this historic complex strengthens the identity of the area and becomes an important point in recognizing and understanding the spatial structure around it.

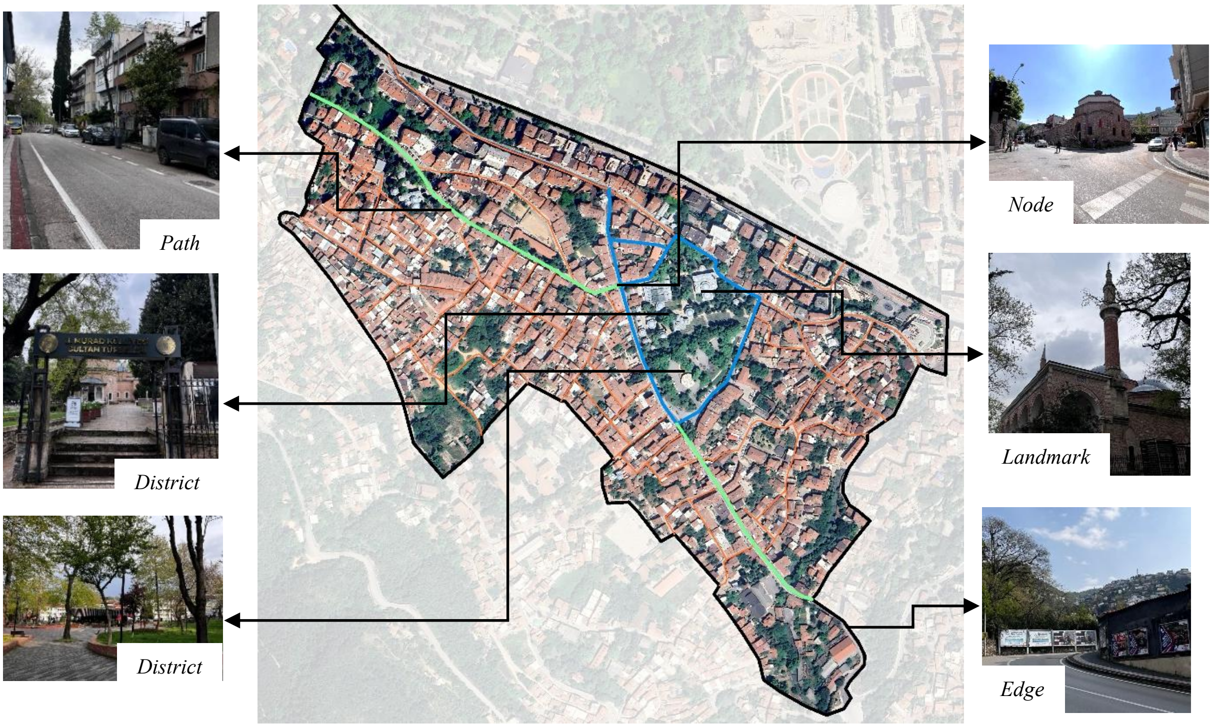

Fig. 9. Image of The Muradiye Külliyesi Historic Area

3.3.2. Spatial Analysis

The concept of landscape planning in the Muradiye Külliyesi area is by dividing zones based on the results of landscape assessment and distributed through the division of functional areas based on user groups such as tourists and residents. This division of zones can support sustainable landscape planning by considering social, economic and environmental in order to maintain the historical value of the Muradiye Külliyesi area.

(1) **Tourist Active Zone (TAZ):** This zone is located in an area that has a concentration of historic buildings and has been evaluated through a spatial and comprehensive landscape assessment process. Based on the results of the evaluation, the area was classified into two categories of Tourist Active Zones, including core zone and supporting zone. The core zone consists of Muradiye Külliyesi and Hamzah Bey Külliyesi, both of which showed the highest landscape quality as well as dominant historical and architectural significance. Meanwhile, other historical buildings such as Osmanlı Ev Museum, Şair Ahmet Paşa Madrasa, Uluumay Osmanlı Halk Kıyafetleri ve Takıları Museum, Hüznü Züber House, and Romangal İpek Fabrikası are functionally categorized in the supporting zones that complement the area's tourist attractions. This classification aims to manage the area based on the preservation of cultural values and optimize the potential of cultural tourism. The existence of this Tourist Active Zone is expected to encourage an increase in tourist flow and contribute to sustainable local economic growth.

(2) **Local Community Zone (LCZ):** The residential neighborhoods in this tourist area play a strategic role in maintaining the social stability of the community while supporting the preservation of historic buildings. These settlements have developed in phases since the past and continue to expand as the growth of Bursa City. The dynamics of settlement growth in this area contributes positively to improving the quality of facilities and infrastructure, both for tourist attractions and for the needs of local residents. In addition, the settlement area also serves as a supporting element for tourism activities through the provision of services, tourist information, and culinary facilities. Therefore, the harmonious development between the Tourist Active Zone and the Local Community Zone is a crucial aspect in supporting the sustainability of tourism activities and improving the welfare of the local community.

(3) **Buffer Zone (BZ):** Sultan Murad II Park is the primary green open space in the area. Its location directly behind the Muradiye Külliyesi complex makes it a transitional element that technically separates the historic zone from the residential area. The park not only functions as an ecological and visual element, but also as a public space that supports social interaction by various user communities. From a spatial point of view, this park is located in a strategic position (in the middle of the area) giving it high accessibility and easily accessible by both local people and tourists. This multifunctional park is an important node in the integration between cultural preservation, environmental comfort, and tourist activities.

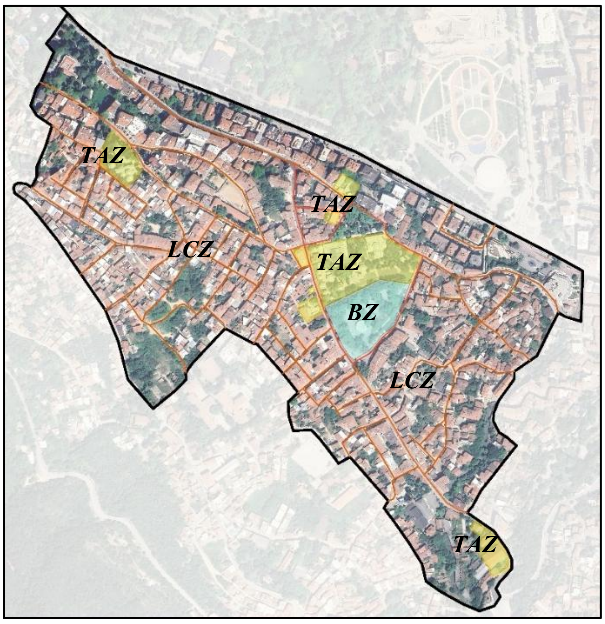

Fig. 10. Planning Zone Distribution in The Muradiye Külliyesi Historic Area

4. Conclusion

The Muradiye Külliyesi area in Bursa, Türkiye, represents an important part of the city's historical and cultural heritage, reflecting the richness of Ottoman architecture and spatial planning. Through the identification and assessment of landscape elements, this study showed that the area has high historical, architectural and spatial value.

The landscape quality assessment results showed that Muradiye Külliyesi and Hamza Bey Külliyesi became the main core zones due to their high level of authenticity, uniqueness and significance. Supporting buildings such as Şair Ahmet Paşa Medresesi, Osmanlı Ev Museum, and others also contribute to enriching the cultural landscape character of the area. Through Kevin Lynch's city image analysis approach, important elements such as paths, edges, districts, nodes, and landmark were identified and carried out to clarify the spatial legibility in the area.

The area planning strategy through the division of zones, which are the Tourist Activity Zone (TAZ), Local Community Zone (LCZ), and Buffer Zone (BZ) is a sustainable approach that emphasizes the balance between preservation, tourism development, and community welfare. This division supports the sustainability of the historic area without ignoring social, economic, and environmental aspects.

Sustainable landscape planning in the Muradiye Külliyesi area does not only preserve cultural and historical values, but also promotes urban livability and sustainable tourism. The methodology can be further improved through community participation. Ultimately, this integrated approach provides a model for the management of other historic areas that have similar challenges and potential.

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The role of public buildings in the urban memory of Ankara

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Abstract. Urban memory encapsulates the spatial, social, and cultural elements that shape a city's identity within collective consciousness. This study explores the role of public buildings in Ankara's urban memory by comparing older (Ulus, Kızılay) and newer (Çayyolu, Yaşamkent) residential areas. Through surveys and mental mapping, it investigates how public buildings are perceived in different spatial contexts. Survey participants evaluated public buildings in terms of accessibility, usage, and contribution to urban identity, while mental mapping revealed perceptual differences between areas. The study emphasizes the significance of spatial continuity and regional mapping in understanding how public buildings are cognitively positioned within the urban landscape. Additionally, it analyzes large-scale public developments, such as city hospitals, focusing on integration with the urban fabric, user accessibility, functional harmony, and the potential to strengthen urban memory. Findings underline the necessity of design strategies that enhance both physical and perceptual connections, especially in newly developed areas. The research proposes human-centered and sustainable urban planning approaches that preserve cultural memory while fostering urban identity. For Ankara, the study recommends reinforcing the perceptual continuity of public buildings, integrating them meaningfully into the urban context, and adopting planning processes that support spatial and symbolic coherence. This work contributes to urban studies by offering strategies to bridge the gap between historical identity and contemporary development, ensuring public buildings remain active components of collective memory.

Keywords: Public building, Urban Memory, Urban identity, Spatial continuity, Cognitive Map.

1. Introduction

Urban memory is a dynamic process that preserves and transmits a city's social, cultural, and spatial characteristics within the collective consciousness (Assmann, 2011). In this context, public buildings function not merely as physical structures but also as carriers of urban identity (Rossi, 1982). As the capital city of Turkey, Ankara has been a significant site where processes of modernization and planned development have been intensely experienced. Accordingly, public buildings hold a special place in the urban memory of Ankara, both physically and symbolically. However, the recent rapid urban sprawl, unplanned construction, and emergence of new residential areas have increasingly called into question the role of public buildings within this collective memory (Erkip, 2000; Altaban, 2009). The physical and functional relationships that public buildings establish with their surroundings directly influence how individuals experience and remember these spaces. While structures located in historical centers such as Ulus and Kızılay stand out as tangible elements of Ankara's modernization process, public buildings in newer residential areas like Çayyolu and Yaşamkent create a comparatively weaker perceptual impact (Tümertekin & Özgüç, 2009). This situation contributes to the weakening of spatial continuity and urban identity.

This study aims to evaluate the role of public buildings in Ankara's urban memory by comparing older (Ulus, Kızılay) and newer (Çayyolu, Yaşamkent) residential areas. It analyzes individuals' perceptions of public buildings, the relationship these structures establish with urban identity, and the degree of spatial continuity. A mixed-methods approach was adopted, incorporating both qualitative and quantitative research methods. Surveys and cognitive mapping (mental mapping) techniques were utilized to uncover how individuals from diverse socio-economic and cultural backgrounds engage with these structures. The study also assesses the extent to which large-scale public projects (such as city hospitals) integrate with the existing urban fabric, their effects on social life, and their potential to reinforce urban memory. Based on the findings, planning and design recommendations have been developed to enhance the perceptual continuity of public buildings and their contributions to urban identity.

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2. Urban Memory and Its Determinants

Urban memory is defined as the sum of the meaning relationships that individuals and communities establish with spaces within the city (Halbwachs, 1992; Lynch, 1960). This memory is recognized as a fundamental component of urban identity, carrying traces of the past into the experiences of the present. As emphasized in Kevin Lynch's seminal work *The Image of the City* (1960), the cognitive images formed by city dwellers play a critical role in shaping how the physical environment is perceived and remembered. These images include squares, public buildings, roads, and other symbolic elements. Pierre Nora's (1989) concept of *lieux de mémoire* (sites of memory) provides a theoretical framework for understanding how specific spaces serve as carriers of collective memory. Structures embedded in the memory of cities are not merely architectural elements; they are spatial reflections of social memory. Public buildings, in particular, play a crucial role in the social production of meaning within urban spaces. Rossi (1982) argues that public buildings are urban elements imbued with "collective memories" and that they constitute the core spaces forming urban identity. Especially institutions such as government offices, courthouses, schools, and hospitals occupy a central place in public life, thus securing a significant position within collective memory (Vale, 2008). These structures are not only functional but also carry symbolic meanings.

In the context of Turkey, public buildings constructed during the early years of the Republic were seen as representations of the modernization process and served as instruments in the construction of a new national identity (Bozdoğan, 2001). The public buildings planned with Ankara's designation as the capital city shaped not only the physical environment but also the collective urban memory. As articulated in Yi-Fu Tuan's (1977) concept of *topophilia*, individuals' emotional attachment to a place is rooted in the meanings attributed to it. Public buildings in older settlements tend to produce this emotional and symbolic meaning more intensely. Thus, public buildings are not merely service delivery points but also key carriers of collective memory. In the framework of Halbwachs' (1992) theory of collective memory, such buildings function as spatial markers of a memorable past. While this function is strongly preserved in historical city centers, the conscious planning of public spaces becomes increasingly necessary to reconstruct public memory in newer residential areas. Moreover, the concept of *place attachment* proposed by Low and Altman (1992) underscores the importance of not only physical continuity but also social and symbolic continuity. Based on these perspectives, this study emphasizes that public buildings should be evaluated not merely for their functional roles but also as spatial elements that reinforce collective memory.

Following the 1980s, Turkish cities underwent a rapid transformation under the influence of neoliberal policies, with urban planning processes increasingly shaped by market dynamics (Keyder & Öncü, 1994). Urban sprawl refers to low-density and often unplanned developments emerging in areas distant from the city center (Bruegmann, 2005). This phenomenon can lead to the fragmentation of spatial integrity and the weakening of urban identity. In Ankara, newly developed areas, particularly those expanding westward—such as Batıkent, Ümitköy, and Çayyolu—are recognized as typical examples of this unplanned sprawl. Public buildings in these areas, often shaped by fragmented planning decisions, have generally failed to fully integrate with the city's identity (Altaban, 2009).

Ankara was initially constructed as a "planned capital" following the proclamation of the Republic. Hermann Jansen's master plan of 1932 proposed a city model centered around public spaces (Tankut, 1990). Public buildings located in central areas such as Ulus and Kızılay were designed in accordance with this plan, intended to serve as the physical representations of the modern and secular Republic of Turkey (Çelik, 1993). However, the increasing population, irregular urban growth, and rising vehicle traffic after the 2000s have begun to diminish the perceptibility and significance of these structures within collective memory. While large-scale public projects have created new centers, the emotional and cultural bonds between these new structures and the broader urban fabric remain weak, making it difficult for such projects to leave a lasting imprint on urban memory (Köksal & Özsoy, 2016).

3. Research Methodology

This research aims to analyze the impacts of public buildings on urban memory in both the older (Ulus, Kızılay) and newer (Çayyolu, Yaşamkent) residential areas of Ankara, focusing on the dimensions of physical and perceptual continuity. The study adopts a mixed-methods approach, combining both qualitative and quantitative research methods. Data were collected through two main techniques: (1) a survey study and (2) cognitive mapping analysis. Through these methods, user experiences, perceptual differences, and levels of spatial continuity were systematically examined.

The survey was conducted with 240 participants selected from the four districts of Ankara (Ulus, Kızılay, Çayyolu, Yaşamkent), representing diverse socio-economic and demographic backgrounds. Participants varied in terms of age, educational attainment, length of residence, and patterns of daily use of public spaces. This diversity enabled a comparative analysis of different spatial experiences and memory patterns (Lynch, 1960; Tuan, 1977).
Within this study, a survey with 240 participants and a cognitive mapping exercise involving 145 participants were employed to reveal the multifaceted position of public buildings within individual and collective memory.

Participants were evenly distributed across demographic variables, and perceptions and feelings of attachment toward public buildings were analyzed based on factors such as age, education, and length of residence (Table 1).

Table 1 Detailed Analysis of the Survey

Variable	*Category*	*Frequency (n)*	*Percentage (%)*
Total Number of Participants		*240*	*100*
Distribution by Region	*Ulus*	*60*	*25*
	Kızılay	*60*	*25*
	Çayyolu	*60*	*25*
	Yaşamkent	*60*	*25*
Age Distribution	*18–30*	*84*	*35*
	31–50	*96*	*40*
	51 and above	*60*	*25*
Gender	*Female*	*128*	*53,3*
	Male	*112*	*46,7*
Educational Level	*High school or below*	*38*	*15,8*
	Bachelor's degree	*122*	*50,8*
	Master's/Doctorate degree	*80*	*33,4*
Length of Residence	*0–5 years*	*56*	*23,3*
	6–15 years	*88*	*36,7*
	16 years ve above	*96*	*40*
Frequency of Public Space Usage	*Several times a week*	*156*	*65*
	Monthly or less	*84*	*35*

The survey form consisted of multiple-choice and open-ended questions designed to examine the physical locations, accessibility levels, frequency of use, environmental integration, and impacts of public buildings on urban identity. Data collected through the survey were analyzed using SPSS software. In the first phase, descriptive statistics (frequency distributions, means, and standard deviations) were calculated. These analyses provided an overview of participant profiles and general trends regarding perceptions of public buildings. In the second phase, cross-tabulations and chi-square (χ^2) tests were conducted to explore the relationships between demographic variables (such as age group, education level, and residential area) and participants' perceptions and usage habits related to public buildings.

The primary aim of the survey was to understand how public buildings are represented in individuals' cognitive maps and how these structures contribute to urban memory. In addition, abstract elements such as spatial continuity and the sense of belonging were analyzed (Altman & Low, 1992). The sample size was determined by considering the standards set by similar studies on urban memory, targeting a minimum 95% confidence level with a ±6.3% margin of error (Neuman, 2014). Participants were selected through purposive sampling, with approximately 60 individuals recruited from each of the four regions. This method aimed to enable an in-depth analysis of the experiences and perceptions of individuals with distinct spatial backgrounds (Patton, 2002). Participants exhibited diversity in terms of age, gender, education level, income status, length of residence, and frequency of public space usage. In the Ulus and Kızılay regions, participants tended to be older, long-term residents with deep-rooted urban experiences. In contrast, newer residential areas such as Çayyolu and Yaşamkent were predominantly inhabited by individuals who had more recently joined urban life, belonged to higher income groups, and were generally younger with relatively shorter durations of urban experience. This diversity allowed for a comparative analysis of different spatial experiences and memory patterns (Lynch, 1960; Tuan, 1977). The survey was conducted through a hybrid method, combining face-to-face interviews with an online questionnaire.

During the cognitive mapping process, participants were asked to create freehand drawings representing public buildings and significant surrounding spaces within their residential areas. These drawings revealed participants' individual perceptions of urban space and the buildings that held a prominent place in their memories. The maps were evaluated based on how structures were represented in terms of scale, orientation, location, and symbolic meaning (Downs & Stea, 1973). The data obtained through cognitive mapping focused not on the physical accuracy of building locations but rather on the symbolic meanings and environmental relationships associated with these structures within urban memory. Although most of the drawings lacked precise spatial scale, they provided valuable insights into the semantic patterns of memory. The findings demonstrated that public buildings assume not only functional roles but also significant emotional and social roles in fostering a sense of belonging (Table 2).

Table 2 Detailed Information on Cognitive Mapping Analysis

Application	Number (n)	Percentage (%)
Number of participants who created cognitive maps	145	60,4
Drawing Method	Hand-drawn maps	92
	Digital map annotation (online)	53
Proportion of maps with building identification	138	95,2
Proportion of maps indicating environmental relationships	119	82,1
Proportion of maps containing semantic value	103	71,0
Number of maps transferred to digital format for GIS-based analysis	145	100

Although approximately 80% of the maps lacked spatial accuracy, they revealed significant patterns in terms of **semantic intensity**. The cognitive maps were digitized and analyzed using **GIS-based software (QGIS and ArcGIS Pro).** Some participants also provided locational indications through an online map-marking tool. The maps were coded according to **three main categories**:

1. **Identified Structures**: The frequency and manner in which public buildings were named and represented.
2. **Environmental Relationships**: The connections established between public buildings and surrounding roads, squares, and green spaces.
3. **Semantic Values**: The meanings attributed to the buildings depicted on the maps (e.g., "the place where I spent my childhood," "the building frequently visited for official procedures").

These categories were thematically classified through **content analysis.**

4. Fieldwork Analysis

The planned urbanization process, which gained momentum with Ankara's designation as the capital city, gradually gave way to uncontrolled urban sprawl and functional fragmentation over time. While the master plans developed since the 1930s primarily structured central areas such as Ulus and Kızılay, post-2000 urban development has been predominantly oriented westward, leading to the emergence of new residential areas like Çayyolu and Yaşamkent (Tekeli, 2011). This spatial rupture has contributed to discontinuities within the city's collective memory.

Ulus and Kızılay represent the planned urban cores of the early Republican period. These areas are characterized by their historical buildings, public institutions, and pedestrian-oriented public spaces. In contrast, Çayyolu and Yaşamkent are defined by large-scale residential projects, shopping malls, and highway connections; however, public life and urban memory in these newer districts remain more fragile and fragmented (Erkip, 2000). According to the survey and cognitive mapping data, participants' perceptions of public buildings varied depending on their residential area. Participants from Ulus and Kızılay associated these buildings with "historical belonging and collective memory," whereas participants from Çayyolu and Yaşamkent primarily referred to public buildings in terms of "accessibility" and "everyday functionality." In older settlements, public buildings were generally located along pedestrian-oriented axes, while in newer residential areas, access was predominantly automobile-dependent. This spatial distinction has also influenced levels of participation in public spaces. Regular use of public buildings was found to be higher among participants from Ulus and Kızılay, whereas visitation frequency was lower in the newer settlements.

Participants described public buildings as contributing more significantly to urban identity in the older districts. In particular, historical structures such as former governor's offices, government mansions, and parliamentary buildings were perceived as "centers of collective memory" (Assmann, 2011). The physical analysis evaluated the spatial placement, environmental connectivity, and functional integration of public buildings. Participants residing in Çayyolu and Yaşamkent exhibited a statistically significant tendency to characterize public buildings as "accessible but lacking a sense of belonging" ($p < 0.05$). Furthermore, the relationship between the contribution of public buildings to urban identity and variables such as frequency of use and accessibility was tested using **Pearson correlation analysis**. The results indicated a strong positive relationship between physical accessibility and cognitive representation ($r = 0.62$; $p < 0.01$). The historical Governor's Building in Ulus was drawn or mentioned by 74% of participants, whereas public service buildings in Yaşamkent were represented by only 31% of participants. The findings align with Lynch's (1960) concepts of "landmarks" and "paths," revealing how individuals navigate and form memories of the urban environment. Cognitive maps were analyzed in comparison with the physical regional map of Ankara. Particularly in the older districts, the denser placement of public buildings within the city center was reflected in higher cognitive visibility. In contrast, public buildings in Çayyolu and Yaşamkent were predominantly represented in a "peripheral" and "neutral" manner. This outcome highlights the parallel between **spatial memory and physical location** (Montello, 2002).

In the perceptual analysis, the visibility and degree of meaning attribution to public buildings in participants' cognitive maps were examined. Within this framework, a direct relationship was identified between the contribution of public buildings to urban memory and their physical spatial arrangement. In the cognitive maps, public buildings located in older settlements were generally positioned at central locations and at the intersections of social interaction networks. In contrast, in newer residential areas, these structures appeared less prominent, situated at marginal locations, and were often described solely through functional terms (Tuan, 1974; Lynch, 1960). While public buildings along the Ulus-Kızılay axis were perceived as key carriers of urban memory, those in the Çayyolu-Yaşamkent areas became increasingly anonymized, with lower levels of identifiability. This difference is attributed not only to the physical characteristics of the structures but also to the continuity of spatial experience. Cognitive maps revealed memory fields that partially overlapped with, but also diverged from, the physical urban maps. In particular, stronger environmental connections between public buildings and their surroundings were represented in Ulus and Kızılay, whereas in the newer settlements, these connections appeared weaker and more fragmented. The degree of physical integration of public buildings with their environment was identified as a critical factor influencing their embedding in urban memory. In Ulus and Kızılay, the organic structure of the urban fabric reinforced the significance of public buildings, whereas in newer areas, artificial and fragmented development patterns weakened these relationships (Jacobs, 1961).

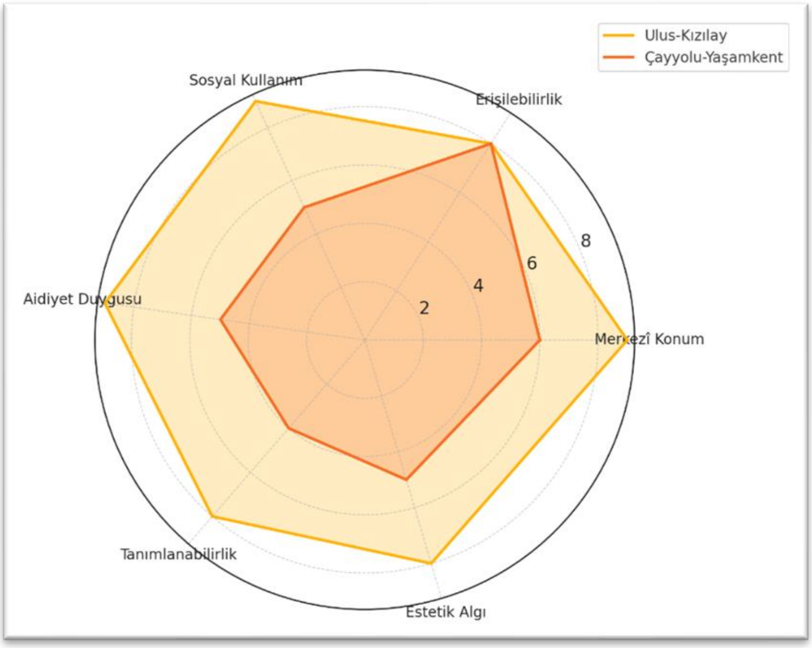

Fig. 1. Comparative Radar Chart of Perceptual Evaluations of Public Buildings in the Ulus-Kızılay and Çayyolu-Yaşamkent Regions

The radar chart (Fig. 1) was created to visualize the regional comparison of perceptual criteria related to public buildings based on the survey data. In this context, participants evaluated key thematic dimensions—such as **central location, accessibility, social use, sense of belonging, identifiability, and aesthetic perception**—using a 10-point Likert scale. The data were separately coded for the **Ulus-Kızılay (older settlements) and Çayyolu-Yaşamkent (newer settlements)** regions, and visualized using a multi-axis radar chart generated with the Python programming language and the matplotlib library. This chart not only provides **a numerical comparison of the survey findings** but also **intuitively illustrates perceptual differences** and their representations within spatial memory. Moreover, it serves as a supportive dataset that strengthens methodological triangulation by aligning with the tendencies identified through the cognitive mapping analyses.

In the radar chart, participants' perceptual evaluations of public buildings in the Ulus–Kızılay and Çayyolu–Yaşamkent regions are **comparatively presented** under six thematic categories. As clearly illustrated in the chart, the **Ulus-Kızılay region** occupies a broader surface area across all dimensions, indicating that public buildings are not only more prominently positioned within the urban fabric but also leave a deeper imprint on participants' cognitive memory. The differences are particularly pronounced in more abstract dimensions such as sense of belonging, **social use, and identifiability**. This finding suggests that public buildings contribute to urban memory not merely through their physical presence but also through their symbolic and social qualities (Tuan, 1977; Halbwachs, 1992). In contrast, although the **Çayyolu-Yaşamkent** region achieves a comparable score in the more technical criterion of accessibility, it displays significantly lower scores across all other dimensions. This outcome indicates that public buildings in newer residential areas lack perceptual continuity and tend **toward anonymity within the collective urban memory** (Lynch, 1960). Furthermore, the radar chart supports the findings from the cognitive mapping analysis, demonstrating that symbolic representations are predominantly concentrated in the older settlements. Thus, the chart serves as a powerful methodological tool, illustrating how survey findings and cognitive mapping analyses collectively produce meaningful insights. It also concretely highlights that spatial perception is shaped not only by **physical planning but also by social interaction, historical attachment, and aesthetic experience.**

Participants reflected their perceptions of the architectural language, scale, and aesthetic integration of the buildings with their surroundings. It was particularly emphasized that historical public buildings evoked feelings of "trust, continuity, and rootedness." The survey data revealed that the social and physical connections established by public buildings with their surrounding environment significantly influence user experience. The presence of elements such as green spaces, bus stops, and public squares enhances the "liveliness" of a public building (Gehl, 2011). It was observed that public buildings function not only as service points but also as spaces of public interaction, serving purposes such as gathering, waiting, and hosting events. This multifunctionality plays a crucial role in the formation of social memory. The association of public buildings with collective memories demonstrates that these structures are powerful not only physically but also symbolically. They help city residents forge connections with the past and preserve a sense of community identity (Halbwachs, 1992). Cognitive maps especially revealed greater visibility for spaces used for events (e.g., ceremonial grounds, cultural performance halls). This finding underscores that experiential engagement with space significantly enhances its memorability within the collective urban consciousness.

The mixed-methods approach employed in this study provided a **multi-layered analysis** by integrating both quantitative and qualitative data collection techniques. Through the survey study, measurable variables such as the physical accessibility of public buildings, frequency of use, and their contribution to urban identity were assessed, while cognitive mapping allowed for the visualization of participants' spatial perceptions, memory traces, and symbolic attributions. This methodological **diversity enabled** the development of a more **holistic understanding**—not only of user experiences but also of how these experiences relate to perceptual continuity (Creswell & Plano Clark, 2018). The high sense of attachment scores attributed to historical public buildings in Ulus and Kızılay in the surveys, combined with their frequent central and symbolic representation in the cognitive maps, serves as a striking example of methodological convergence. This integrated approach also revealed the intersections between spatial context and social memory. The visual representations that emerged from the cognitive maps demonstrated that individuals' relationships with space are shaped not solely by physical location but also by subjective layers such as past experiences, collective memory, and aesthetic perception. This finding aligns closely with Lynch's (1960) principle of **"visual identifiability"** and Tuan's (1977) concept of "emotional attachment." Moreover, by digitally processing the cognitive maps and comparing them with regional physical maps, mismatches between cognitive perception and the physical environment were also identified. In planned but emotionally detached areas such as Çayyolu and Yaşamkent, despite the strong physical presence of public buildings, their weak representation in cognitive maps clearly illustrated that physical existence alone is **insufficient for the formation of urban memory** (Montello, 2002). Therefore, cross-methodological comparisons not only enhanced data diversity but also significantly enriched the conceptual depth of the study.

The findings of the study (Table 1) reveal that the role of public buildings in urban memory differs spatially and cognitively between the older (Ulus-Kızılay) and newer (Çayyolu-Yaşamkent) residential areas of Ankara. According to the survey results, public buildings located in Ulus and Kızılay occupy a strong position in participants' memories; these structures evoke a high degree of identifiability and a sense of belonging through the historical continuity established with daily life. A similar tendency was observed in the cognitive maps, where public buildings in the older centers were represented more frequently and with greater detail. This pattern indicates that spatial memory is firmly established in these areas and that public buildings serve as foundational elements in the construction of collective urban memory. The convergence between the quantitative and qualitative findings underscores the significance of public buildings not merely as functional spaces but also as symbolic anchors of historical and social continuity within the urban fabric.

An examination of the spatial positioning of public buildings within the urban fabric reveals that, according to the survey data, these structures maintain a central character in the older districts, whereas in the newer residential areas, they are distributed in a more dispersed and directionless manner. This spatial fragmentation is also reflected in the cognitive maps: in Ulus and Kızılay, public buildings were predominantly placed near the center of the maps, while in Çayyolu and Yaşamkent, their positional ambiguity was notable. The frequency of use of public buildings as venues for social activities emerged as another factor influencing spatial memory. In the older centers, public buildings hosted a variety of social, cultural, and administrative activities, whereas in the newer districts, such functions were weaker, resulting in a more limited imprint on collective memory. Regarding the sense of belonging and identity, public buildings with historical and symbolic value were found to be more strongly represented in the older areas, while the potential of buildings in newer settlements to foster a sense of belonging remained limited. This difference is clearly evident in both the survey findings and the cognitive maps.

In terms of physical accessibility, the functional adequacy and ease of access to public buildings were particularly emphasized in the Ulus-Kızılay region. This was visually expressed in the maps through the distinctiveness of road networks and the proximity of public buildings to major transportation hubs.

A more complex pattern emerged concerning environmental integration and aesthetic perception. Participants noted that historical buildings were more harmoniously integrated into their surroundings and exhibited distinctive aesthetic qualities, a finding supported by the detailed representation of these structures in cognitive maps. In contrast, public buildings in newer areas were often perceived as neutral, lacking in aesthetic significance, and occupying a more marginal position in memory. Finally, regarding identifiability, public buildings in the older centers were recognized as symbolic landmarks, whereas in newer areas, despite their physical presence, they remained largely cognitively anonymous. The absence or vague representation of these structures in cognitive maps indicates that their physical existence did not translate into a symbolic presence within the urban memory.

Table 3. Methodological Convergence and Divergence Between Survey and Cognitive Mapping Findings in Terms of Urban Memory

Criteria	Survey Findings	Cognitive Mapping Findings	Analysis
Position of public buildings in memory	High in Ulus-Kızılay, low in Çayyolu-Yaşamkent	Consistent; denser representation in older centers	High convergence – strong spatial memory
Central location of public buildings	Centrally located in older centers, dispersed in newer areas	Ulus-Kızılay positioned at the center of cognitive maps	Full convergence – high cognitive visibility
Use of public buildings as social activity spaces	Regular use in Ulus-Kızılay; rare in newer areas	Social spaces more frequently represented in older centers	Convergent – social functions leave a memory trace
Sense of belonging and identity	High attachment to historical buildings; neutral in newer ones	Symbolic structures represented only in older areas	Convergent – belonging linked to symbolic value
Physical accessibility	High accessibility and functional adequacy	Physical access also indicated in cognitive maps	Supportive – physical features embedded in memory
Environmental integration and aesthetics	Harmonious in historical context; weak in newer area	Aesthetic elements drawn more detailed for historical buildings	Partial convergence – stronger entry into historical aesthetic memory
Identifiability of public buildings	Symbolic in Ulus-Kızılay; anonymous in new areas	Vague representations in new areas; lack of symbolic features	Divergence – physical presence but weak cognitive perception

The comparative analysis of the survey and cognitive mapping findings presents a strong methodological intersection in terms of **data integrity and validity**. In particular, the relationship between the physical centrality of public buildings and their visibility in individuals' cognitive representations is consistently reflected across both the survey and cognitive map data. Survey findings indicate that public buildings in older residential areas such as Ulus and Kızılay are characterized as centrally located, highly accessible, and frequently used structures. This pattern is corroborated by the cognitive maps, where these buildings are positioned centrally alongside other significant spatial references. This finding directly aligns with Kevin Lynch's (1960) concept of *imageability*, which posits that higher perceptibility within urban space enhances the prominence and functionality of that space in individuals' cognitive maps.

In this study, the high degree of representation of public buildings in Ulus and Kızılay—both in terms of physical positioning and cognitive visibility—supports this theoretical framework. Methodologically, this convergence strengthens the reliability of the mixed-methods approach employed; the consistency of results obtained through different data collection techniques reinforces the study's **internal validity and enhances data triangulation** (Creswell & Plano Clark, 2018). Accordingly, the observed consistency between spatial organization and cognitive perception carries both theoretical and practical significance for understanding how public buildings are positioned within urban memory.

5. Conclusions

The methodological structure of this study was deliberately built upon a **mixed-methods approach to enable a comprehensive analysis** of the role of public buildings in urban memory. Quantitative indicators derived from the **survey data** and **qualitative pattern**s emerging from the cognitive maps mutually reinforced one another, generating a multidimensional understanding. Within this framework, **data triangulation** was employed to test the consistency of findings obtained from different sources, thereby ensuring the methodological **validity of the results** (Creswell & Plano Clark, 2018). The identification of public buildings in Ulus and Kızılay as having high levels of attachment and usage in the survey data, coupled with their frequent representation in cognitive maps, stands as a strong outcome of this integrated structure. Similarly, the matching of cognitive maps with spatial analyses in digital environments enabled the establishment of meaningful connections between physical placement and perceptual representations.

This comparative analysis not only provided insights into spatial organization but also revealed the extent to which individual experience, social context, and symbolic meanings influence the formation of urban memory (Montello, 2002; Tuan, 1977). Therefore, one of the most significant contributions of this study is its ability to articulate the relationship between **physical space** and **collective memory at both measurable and semantic levels**. This framework also forms the basis for the recommendations presented in the subsequent sections, ensuring that they are grounded both technically and culturally

The research findings demonstrate that the physical locations of public buildings and their relationships with the surrounding environment play a significant role in determining their place within urban memory. It was observed that in historical centers such as Ulus and Kızılay, public buildings are more visible and meaningful in both individual and collective memory, whereas in newer residential areas such as Çayyolu and Yaşamkent, these structures, although functionally utilized, remain perceptually less prominent. This finding aligns with Kevin Lynch's (1960) principles of *visibility* and *identifiability*.

Based on the case of Ankara, the following recommendations have been developed:

- The site selection of public buildings should consider regional memory and the cultivation of a sense of collective belonging.
- In new residential developments, public buildings should be integrated with symbolic elements that contribute to the construction of public memory, such as squares, monuments, and ceremonial spaces.
- Urban planning strategies should account not only for accessibility but also for spatial continuity and the potential for public engagement and use.

It has been understood that the presence of public buildings in urban memory is not solely determined by their physical existence, but rather shaped by multidimensional factors such as user experience, event memory, and spatial context. Particularly in the historical centers, public buildings have been anchored in memory through experiences carried from childhood to the present, whereas in newer districts, the construction of such continuity still needs to be fostered. This highlights the necessity for urban planning policies to emphasize not only physical aspects but also symbolic connections. This study specifically analyzed the role of public buildings in urban memory within the case of Ankara. However, future research could expand upon this work by conducting comparative studies across different cities, focusing on various age groups or user types (such as individuals with disabilities, children, or migrants), and integrating digital mapping and AI-supported perception analysis with urban memory research. Building perceptual bridges between older and newer settlements is crucial. Site selection processes should be informed by participatory planning practices grounded in user experiences, where memory itself becomes an input for urban design. Ultimately, to strengthen the role of public buildings within urban memory, the following recommendations are proposed: public buildings must be not only physically accessible but also symbolically meaningful. The strong memory traces associated with historical districts should be preserved, while in newer areas, experiential spaces that can cultivate memory must be created. Moreover, the relationship between public buildings and their surroundings should be designed in social, aesthetic, and functional terms.

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Representation of disadvantaged groups in the education of professions influential in spatial production

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Abstract
Urban spaces are the settings of daily life and are used by heterogeneous groups of people. Despite sharing the same physical spaces, individuals may have vastly different experiences. Given that spatial regulations are typically shaped by certain standards and generalizations, disadvantaged groups—compared to healthy and male individuals—often exhibit heightened spatial sensitivities. In professional fields such as architecture, urban and regional planning, and landscape architecture, the promotion of inclusive planning and design approaches within educational processes serves as a critical tool in achieving spatial equity for vulnerable groups.

In this context, the aim of the study is to analyze the presence and content of courses addressing disadvantaged groups (e.g., women, the elderly, children, individuals with special needs) within the undergraduate, graduate, and doctoral curricula of architecture, urban and regional planning, and landscape architecture departments in universities across Turkey. The study seeks to answer the following research questions: "At which educational level are courses on the design of the built environment for disadvantaged individuals concentrated?", "What themes are addressed in these courses?", and "Do these courses vary across different educational levels (undergraduate, graduate, doctoral)?". The objectives and contents of both compulsory and elective courses in relevant departments of public universities were subjected to qualitative content analysis, and the data were analyzed using the Maxqda 24 software.Considering the three educational levels, 47 relevant courses were identified in Architecture, 33 in Urban and Regional Planning, and 28 in Landscape Architecture—figures that remain relatively low in light of the current curricula.

Keywords: Disadvantaged individuals; Spatial design; Planning;Content analysis

1. Introduction

Space, defined as the place of a person or group, encompasses a range of spatial scales—from small physical areas to broader contexts such as our homes, neighborhoods, cities, regions, and nations, extending up to the global level. Societies are composed of heterogeneous groups of people, and while individuals may occupy the same spaces, their experiences can differ significantly. When spatial arrangements are typically guided by generalized standards and norms, certain users may be adversely affected by such frameworks. In particular, women, older adults, children, and individuals with special needs (i.e., disadvantaged groups) tend to exhibit greater spatial sensitivity compared to healthy, male individuals. Although often unintentional, the failure to account for the specific needs and priorities of these groups during spatial design processes can result in negative impacts on their lives.

Issues such as women's access to and safe use of public spaces, children's integration into play and social environments, mobility for the elderly, and accessibility demands of individuals with special needs represent distinct and critical concerns that must be considered in built environment design. Integrating these needs into spatial planning and design processes not only enhances individual quality of life but also strengthens social cohesion and the notion of inclusive cities. Design approaches that address the spatial needs of disadvantaged groups must go beyond basic physical accessibility and safety to also encompass opportunities for social interaction, psychological well-being, and self-realization.

In the planning and design of housing, transportation, open and green spaces, public spaces, and urban services—which directly shape daily life practices—students in architecture, urban and regional planning, and landscape architecture must adopt an inclusive and equity-oriented perspective that recognizes individual and

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social differences. In this regard, enhancing inclusive planning and design approaches in both the professional practice and educational curricula of architecture, urban and regional planning, and landscape architecture plays a vital role in achieving spatial equity for vulnerable populations.

Architecture is a discipline concerned with designing and constructing human environments in accordance with aesthetic, functional, and technical principles. Vitruvius's triad of "firmness, utility, and beauty" (*firmitas, utilitas, venustas*) (Vitruvius, 1st century BCE) still constitutes the foundational pillars of architectural education and practice today. Architectural education aims to cultivate students' creative thinking, technical skills, and sense of social responsibility (Salama, 2015). Urban and regional planning is a discipline that guides the economic, social, environmental, and spatial development of settlements and regions. According to the United Nations Human Settlements Programme (UN-Habitat, 2020), urban planning serves as a tool to promote social justice, environmental sustainability, and economic efficiency. Landscape architecture, on the other hand, involves the design of natural and built environments to serve aesthetic, ecological, and social functions. As defined by the American Society of Landscape Architects (ASLA, 2021), the discipline encompasses the sustainable management of open spaces, urban areas, and natural systems, aiming to create healthy, livable environments through the integration of ecological, sociological, and aesthetic principles.

These disciplines play a critical role in shaping the built environment, which directly affects individual quality of life. Their curricula typically consist of studio courses (applied project work), theoretical courses, and technical courses. Architecture programs often emphasize foundational design studios, building technologies, architectural history, building physics, and urban studies. Urban and regional planning curricula tend to focus on planning theory, spatial analysis, transportation planning, and environmental planning. In landscape architecture programs, courses in ecology, plant materials, design studios, and environmental planning are prioritized. While required courses in these disciplines largely focus on technical and theoretical knowledge transfer, issues concerning social sensitivity and disadvantaged groups are often relegated to elective courses (Salama, 2016; Dovey, 2010). This trend is also observed in curricula across Turkish universities (Erbaş & Yücesoy, 2018).

In recent years, leading universities around the world have begun to offer more inclusive courses addressing the needs of disadvantaged groups. For example, the Harvard Graduate School of Design (GSD) offers courses such as *Urban Inclusion and Social Equity*, which focus on spatial rights and social equity in urban planning (Harvard GSD, 2022). University College London (UCL), through its Bartlett Faculty of the Built Environment, offers *Designing Inclusive Places*, addressing the representation of groups such as the elderly, children, and individuals with disabilities in urban spaces (UCL Bartlett, 2021). Similarly, Delft University of Technology (TU Delft) offers the *Inclusive Environments* course, which introduces architecture students to the importance of addressing diversity in design at both conceptual and practical levels (TU Delft, 2020).

Despite such progress, literature reviews indicate that most architecture and planning programs still inadequately address the spatial needs of disadvantaged groups in their core curricula (Ahrentzen, 2015; Salama, 2016). Ahrentzen (2015) argues that architectural education is often based on the idea of an "average user" and fails to sufficiently accommodate differences. Although universal design principles have been internationally recognized (Center for Universal Design, 1997), their integration into academic curricula remains inconsistent. Particularly at the undergraduate level, inclusive design approaches are not systematically incorporated into studio instruction (Heylighen, 2012).

The United Nations' Sustainable Development Goals (SDGs), comprising 17 global objectives to be achieved by 2030, aim to end poverty, protect planetary sustainability, and enhance human well-being. Among these, Goal 5 promotes gender equality and the empowerment of women and girls, while Goal 11 advocates for inclusive, safe, resilient, and sustainable cities and human settlements (UN-Habitat, 2020). In this context, it is expected that education in planning and design disciplines should reflect these goals by incorporating socially inclusive and equitable content. However, literature suggests that these goals are often addressed at the policy level without being meaningfully integrated into academic curricula (Alawadi, 2020; Madanipour, 2006). Even when SDGs are referenced in educational programs, the connection is often superficial, with little application in design studios or project-based learning (UNESCO-UIA Charter, 2017).

Against this backdrop, the aim of this study is to examine the presence and content of courses addressing disadvantaged individuals (e.g., women, the elderly, children, and individuals with special needs) in undergraduate, graduate, and doctoral curricula within architecture, urban and regional planning, and landscape architecture departments at universities in Turkey. The research seeks to answer the following questions: "At which educational levels are courses on the design of the built environment for disadvantaged individuals most concentrated?", "What themes are covered in these courses?", and "Do these courses vary across different educational levels (undergraduate, graduate, doctoral)?"

2. Research Methodology

This study investigates the presence and content of courses aimed at disadvantaged users within the undergraduate, graduate, and doctoral programs of architecture, urban and regional planning, and landscape architecture departments—disciplines that play a key role in the production of space and the built environment—in universities operating in Turkey. According to 2024 data from the Turkish Higher Education Council (YÖK) Atlas, there are 167 architecture, 41 urban and regional planning, and 42 landscape architecture undergraduate programs offered by public and foundation universities in the country (URL 1). Within the scope of this research, only programs at public universities that rank among the top 15 in national university entrance rankings or that enroll 20 or more students were included.

In cases where a single university hosts two or all three of these departments, all relevant departments were considered. Consequently, the study examined the undergraduate, graduate, and doctoral programs of departments in 32 public universities. Both compulsory and elective courses were included, and their objectives and contents were analyzed using qualitative content analysis. The data were processed and analyzed with the Maxqda 24 software. Course information was obtained by accessing the official websites of the respective departments and reviewing the available course catalogs.

Table 1 presents the number of undergraduate, graduate, and doctoral programs in architecture, urban and regional planning, and landscape architecture departments at the selected 32 public universities. Due to its earlier establishment in Turkish higher education compared to the other two disciplines, the number of architecture programs is relatively higher.

Table 1. Number of educational programs in relevant departments (Compiled by authors)

	Architecture	Urban and Regional Planning	Landscape Architecture
Undergraduate	26	26	16
Master's	23	17	14
Doctorate	20	13	13

3. Findings

A total of 108 courses addressing disadvantaged individuals were identified in departments of Architecture, Urban and Regional Planning (URP), and Landscape Architecture that offer education at least at one of the levels of undergraduate, master's, or doctorate. As shown in Table 2, the distribution of these courses by department indicates that 47 are in Architecture, 33 in URP, and 28 in Landscape Architecture. When examining the distribution of these courses across educational levels, 75 are at the undergraduate level, 17 at the master's level, and 16 at the doctoral level.

In terms of the proportion of courses within each educational level, Architecture departments at the doctoral level have the highest rate of courses on disadvantaged groups at 3.1%. This is followed by URP undergraduate programs (2.9%) and Landscape Architecture undergraduate programs (2.6%). The Landscape Architecture doctoral programs have the lowest rate, with only 1.3% of courses addressing these topics.

Table 2. Distribution of courses addressing disadvantaged groups across educational levels and departments

	Programs														
	Undergraduate					Master's					Doctorate				
Departments	Other Courses		Courses Addressing Disadvantaged		Total Number of Courses	Other Courses		Courses Addressing Disadvantaged		Total Number of Courses	Other Courses		Courses Addressing Disadvantaged		Total Number of Courses
	N	%	N	%		N	%	N	%		N	%	N	%	
Architecture	1137	97,5	30	2,5	1167	331	97,7	8	2,3	339	280	96,9	9	3,1	289
Urban and Regional Planning	804	97,1	24	2,9	828	234	98	5	2	239	153	97,5	4	2,5	157
Landscape Architecture	785	97,4	21	2,6	806	243	98,4	4	1,6	247	218	98,7	3	1,3	221

Universities are expected to contribute to their respective professional fields, particularly within their cities, regions, and at the national level. Equipping professionals involved in the production of the built environment/space with the necessary knowledge and skills to address the needs of disadvantaged individuals is crucial for achieving Gender Equality (SDG 5) and Sustainable Cities and Communities (SDG 11). When all state university programs in architecture, urban and regional planning, and landscape architecture in Türkiye are evaluated collectively, it becomes evident that the proportion of such courses is highest in the relevant departments located in Istanbul (Fig. 1). This is followed by departments in the Marmara Region. Despite its geographical distance from central regions, the high proportion of such courses at Karadeniz Technical University is also noteworthy. This may be explained by the fact that the relevant departments at KTÜ were among the first to be established in the country.

UNIVERSITY NAME	NUMBER OF COURSES	UNIVERSITY NAME	NUMBER OF COURSES	UNIVERSITY NAME	NUMBER OF COURSES
İstanbul Teknik Ünv.	16	Bursa Teknik Ünv.	4	Ortadoğu Tek. Ünv.	1
Yıldız Teknik Ünv.	13	İzmir Demokrasi Ünv.	4	İzmir Yüksek Tek. Ünv.	1
Mimar Sinan Güz. San. Ünv.	11	Onsekiz Mart Ünv.	4	İstanbul Ünv.	1
Bursa Uludağ Ünv.	9	Gebze Teknik Ünv.	3	Eskişehir Teknik Ünv.	1
Karadeniz Teknik Ünv.	8	Atatürk Ünv.	2	Osman Gazi Ünv.	1
Necmettin Erbakan Ünv.	8	Ege Ünv.	2	Cerrahpaşa Ünv.	1
Gazi Ünv.	6	Ankara Ünv.	2	Pamukkale Ünv.	1
Konya Teknik Ünv.	6	Namık Kemal Ünv.	2		

Fig. 1. Universities in Türkiye Offering Courses Focused on Disadvantaged Groups and Their Geographical Locations

4. Thematic Content Analyses of the Courses

A total of 108 courses from the departments of Architecture, Urban and Regional Planning (URP), and Landscape Architecture were examined. Course objectives and contents were accessed from online course information packages; courses without publicly available information were excluded from the evaluation. The objectives and contents of the courses were subjected to content analysis in the Maxqda program, and separate word clouds were generated for each department, followed by a combined word cloud for all departments. Word clouds are a tool used in content analysis methods within social sciences. These visual representations highlight the frequency of words in a text, but they do not provide deeper linguistic analysis (Jones, 2018). Word clouds are a visualization tool that quickly highlights important words in large datasets and allow users to easily identify key terms in the content (Brown, 2017). In these visuals, there is a linear relationship between the size of a word and its frequency of use in the text.

When analyzing the word clouds created based on the themes/concepts in the course content of departments providing professional education in spatial production processes, differences between the departments are evident. In the Architecture department, “universal design” stands out; in URP, “urban design” is prominent; and in Landscape Architecture, the themes of “child” and “play” come to the fore. When all departments are evaluated together, it was found that the most frequently used themes, in order, are universal design, social, community, and urban design (Table 3).

Table 3. Word clouds based on course content in the departments

Department of Architecture

Department of Urban and Regional Planning

Department of Landscape Architecture

All Departments

When all courses across the three departments and educational levels are evaluated collectively, the themes of design, social dimension, environmental dynamics, behavior & perception, and planning & the city emerge as prominent. The frequency and sub-themes of each theme/concept, based on course content, are listed below:

1. Design: Identified in 10 courses, encompassing various sub-topics such as Universal Design and User-Centered Design.
2. Social Dimension: Found in 8 courses, covering topics such as gender, inequality, and inclusivity.
3. Environmental Dynamics: Present in 6 courses, addressing issues like environmental psychology and sustainability.
4. Behavior & Perception: Observed in 5 courses, including subjects related to spatial behavior and perception.
5. Planning & the City: Featured in 4 courses, encompassing themes such as urban design and public spaces.

Undergraduate education is structured to provide foundational knowledge necessary for entering professional life. While the master's level aims to develop specialization in a specific field, doctoral education is designed to enable original academic contributions within the relevant professional domain. Therefore, the content and depth of courses at these three educational levels differ significantly.When courses related to disadvantaged groups are evaluated in general terms, the following themes emerge: at the undergraduate level, accessibility and environmental psychology; at the master’s level, environmental psychology and gender; and at the doctoral level, user-centered design and the psychology of disability.An analysis of the content of both compulsory and elective courses across all three educational levels reveals that compulsory courses primarily focus on accessibility (Design for All and universal design principles), environmental psychology (human-environment interaction and behaviors), and gender (the spatial implications of gender). In contrast, elective courses prioritize themes such as children's play spaces, barrier-free design, and user-centered design.

The analysis conducted to identify the thematic focuses within the departments of Architecture, Urban and Regional Planning, and Landscape Architecture revealed three overarching themes across all disciplines: accessibility (a significant focus area in each department), environmental psychology (a critical theme for understanding human behavior in spatial design), and gender (studies on the role and impact of gender in spatial design).When examined separately by department, thematic focuses in the Architecture department include accessibility, environmental psychology, gender, and design for all. In the Urban and Regional Planning (URP) department, the prominent themes are urban space and human interaction, gender and space, child-friendly cities, and the psychology of disability. In the Landscape Architecture department, key focuses include accessible landscape design, children's play areas, universal design, and environmental impacts.These conceptual relationships among themes are also detailed in the departments' conceptual network diagrams (Fig. 2).

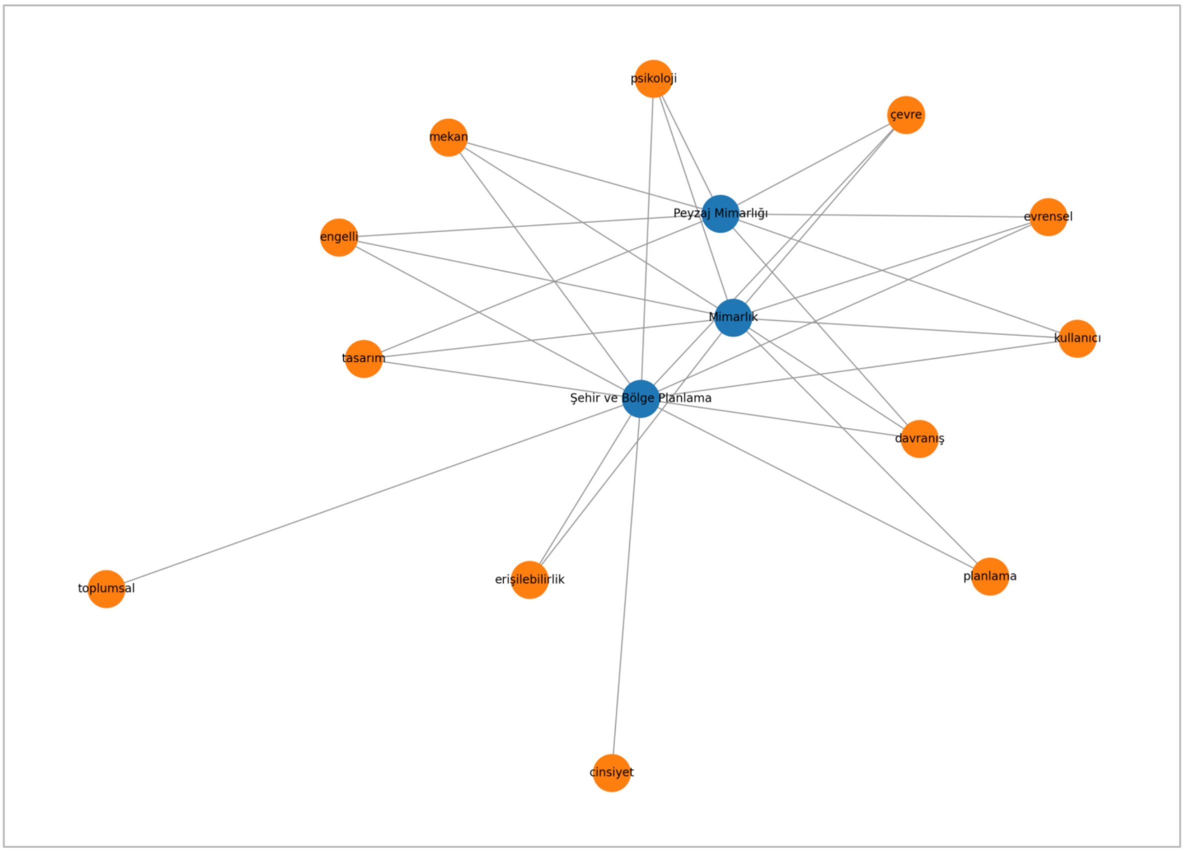

Fig. 2. Departments and conceptual relationship networks

In architecture, urban and regional planning, and landscape architecture departments offering undergraduate, master's, and doctoral education in Turkey, the following themes have been identified as underrepresented in courses addressing the needs of disadvantaged groups:

1. Child-Friendly Design: Studies focusing on children's use of space and their specific needs are less prevalent than expected. This theme particularly emphasizes children's play areas and their experiences within urban environments.
2. Disability Psychology: Courses addressing the psychological needs of individuals with disabilities and the spatial implications of these needs are limited. This theme is of critical importance in terms of spatial use and social integration of people with disabilities.
3. Gender and Space: The impact of gender on space is not sufficiently explored in depth at some universities. This theme offers a crucial perspective on gender equality and spatial justice.
4. Sustainable Design: The theme of sustainability is less frequently covered than expected, particularly in architecture and urban planning curricula. It is essential for reducing environmental impacts and creating sustainable living environments.

5. Conclusion

In Turkey, the number of courses addressing the needs of women, the elderly, children, and individuals with special needs within undergraduate, master's, and doctoral curricula in the departments of architecture, urban and regional planning, and landscape architecture remains quite limited. The existing course contents tend to concentrate on specific themes. Undergraduate education, in particular, holds critical importance for cultivating well-qualified professionals. In all three departments, the proportion of such courses at the undergraduate level is approximately 2.5%, and these are offered as elective courses. The predominance of technical and general design-oriented compulsory courses at the undergraduate level results in issues such as social equity and inclusivity being relegated to the periphery of the curriculum, addressed only through electives.

The proportion of relevant courses at the master's and doctoral levels is similarly low, averaging around 2.5% across all three departments. The curriculum at these levels in the field of landscape architecture falls below this average. Enhancing the number and content of such courses is of vital importance for advancing expertise at the doctoral level, which can contribute to the professional fields from the perspective of producing equitable spaces for disadvantaged groups.

Despite global frameworks such as the United Nations Sustainable Development Goals emphasizing and promoting inclusive space-making, academic programs in Turkey have yet to fully align with these objectives. Moreover, there is a clear need for systematic efforts to cultivate a highly qualified professional workforce and domain-specific experts. Centralizing principles such as social justice, accessibility, and diversity within educational programs is a critical step toward creating sustainable and just cities and public spaces.

The richness of academic staff in Turkey's leading universities in the fields of architecture and planning has brought with it greater diversity in course offerings. However, there are significant regional disparities in the availability of courses focused on disadvantaged groups. Particularly in recently established departments with limited academic personnel, such courses are often absent from the curriculum. Given that universities are expected to contribute first to their local and regional contexts, and subsequently to national professional development, incorporating the courses examined in this study into departmental curricula in a way that addresses regional disparities is both a necessary and urgent priority. Expanding the number and enriching the content of inclusive and equity-focused courses in academic curricula is essential for building sustainable societies and livable urban environments. In line with this objective, it is also recommended that departments commence instruction in these areas only when they have reached a sufficient number of academically qualified staff equipped with the necessary disciplinary expertise.

Acknowledgements and Statement

This paper analyzes course content in architecture and planning education with a focus on disadvantaged groups, revealing the current state of inclusivity and social equity. In alignment with the Sustainable Development Goals, the study emphasizes the need to transform curricula to promote a more equitable and accessible built environment. I would like to express my gratitude to my academic advisor for their invaluable support, to my colleagues who contributed during the data collection and analysis processes, and to the universities that provided open-access resources. I am also thankful for the national and international academic sources that guided the content analysis.

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A multi-criteria decision-making framework for optimal sustainable facade selection in residential buildings of Tabriz

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Abstract. This research introduces a robust multi-criteria decision-making (MCDM) framework designed to evaluate and prioritize sustainable facade options specifically for residential buildings in Tabriz, Iran. Addressing the city's distinct cold semi-arid climate and valued architectural heritage, this study explicitly incorporates local climatic challenges, architectural identity considerations, and urban context specifics. A comprehensive set of evaluation criteria—encompassing aesthetic, environmental, economic, and technical dimensions—was meticulously derived from literature and regional expert consultation. The Analytic Hierarchy Process (AHP) was strategically employed to quantify the relative importance of these criteria, authentically reflecting priorities of key local stakeholders (residents, architects, municipal officials). Subsequently, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was utilized to rank fourteen diverse facade alternatives (including conventional, smart, and green types). AHP results revealed compatibility with the urban context and aesthetic quality as paramount criteria for Tabriz stakeholders, a potentially distinguishing regional finding. The TOPSIS analysis identified smart and green facades as the most advantageous options, exhibiting superior overall performance, particularly in energy efficiency and environmental impact, corroborated by quantitative energy simulations. This study's primary contribution is a validated, context-sensitive framework for optimizing facade selection, uniquely integrating subjective local priorities with objective performance data. Findings offer actionable guidance for advancing sustainable building practices in Tabriz and analogous settings.

Keywords: Sustainable facade; Residential buildings; Multi-criteria decision-making (MCDM); Tabriz; Context-specific design

1. Introduction

The global proliferation of multi-story construction presents significant sustainability challenges concerning resource depletion and environmental degradation (Ghasemi Gilvaei & Ghorbani Param, 2024). This global trend impacts Iranian cities like Tabriz, where rapid urbanization interfaces with distinct environmental conditions and cultural heritage (Rahnama & Abbaszadeh, 2006; Gorji Mahlabani, 2010). Building facades, as the critical interface between interior and exterior environments, profoundly influence building energy performance, occupant thermal and visual comfort, and the overall urban aesthetic (Ahmadi et al., 2019). Consequently, facade selection represents an increasingly complex design problem, demanding sophisticated trade-offs among energy performance, environmental footprint (including embodied impacts), life-cycle cost-effectiveness, technical durability, and aesthetic integration within the urban fabric (e.g., Shafiee et al., 2022). For Tabriz, characterized by a cold semi-arid climate necessitating substantial heating energy and possessing a unique architectural identity demanding preservation, the imperative for contextually sensitive, high-performance facades is particularly acute. This need is amplified by known issues and deficiencies in the facade treatments applied to a significant portion of the city's building stock, highlighting an urgent need for effective sustainable solutions.

Sustainable facade design endeavors to mitigate environmental impact, enhance occupant well-being, and preserve urban character through informed material selection, resource management, and appropriate technology integration (Pearce et al., 1989; Abbaspour, 2007; Rogers, 2007). However, achieving an optimal balance among diverse criteria—aesthetics, environmental sustainability, cost-effectiveness, technical feasibility, and urban compatibility—remains a central challenge (Ghodsipour, 2006). Although global research on sustainable facades is extensive, context-specific assessments that rigorously integrate local climatic data, urban fabric constraints, and crucially, socio-cultural stakeholder priorities remain scarce, particularly for cities like Tabriz exhibiting such distinct characteristics. This study directly addresses this gap. Multi-Criteria Decision-Making (MCDM) methodologies provide structured, transparent frameworks ideal for tackling such complex decision problems

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(Zavadskas et al., 2024; Cinelli et al., 2022). Therefore, this research develops and validates an optimal sustainable facade selection framework tailored for low-rise residential buildings (<10 stories) in Tabriz (District 1), utilizing an integrated approach combining the Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution 1 (TOPSIS), augmented by energy simulation. The novelty of this work lies in its specific application to the under-researched Tabriz context, its integration of quantitatively assessed local stakeholder priorities (particularly the high value placed on aesthetics and context) with objective performance data, and the resulting provision of localized, actionable recommendations.

2. Materials and Methods

This study employed a sequential mixed-method design integrating expert surveys, MCDM modeling, and building energy simulation. The overall process of this research is shown in Fig. 1 as a flowchart.

2.1. Criteria and Alternatives Identification

Nine key evaluation criteria pertinent to facade sustainability within the Tabriz context were systematically identified: Energy Consumption (-), Aesthetics (+), Compatibility with Urban Architecture (+), Environment/Sustainability (+), Cost (-), Implementation Time (-), Maintenance (-), Contractor Skill (+), and Ease of Procurement/Execution (+). Fourteen representative facade systems were evaluated: Natural Stone, Natural Stone Composite, Artificial Stone, Glass Curtain Wall, Aluminum Composite Panel, Bayramix, Ceramic Tile, Brick, Monolithic Cement Render, Standard Cement Render, Expanded Metal Mesh, Timber Cladding, Green Facade, and Smart (Adaptive) Facade.

2.2. Data collection

Data collection involved literature synthesis, review of relevant official reports and standards, and field surveys. Structured questionnaires and interviews were conducted with 71 purposively selected local experts (architects, developers, contractors, municipal officials) to elicit judgments on criteria importance and alternative performance.

2.3. MCDM Framework

The synergistic application of AHP and TOPSIS was chosen for its suitability. AHP effectively handles the hierarchical structuring of the decision problem and captures subjective expert judgments for criteria weighting. TOPSIS provides a rational and practical method for ranking alternatives based on multi-attribute performance relative to ideal solutions. This combined AHP-TOPSIS methodology is well-established for complex selection problems in building design and engineering (Jagarajan et al., 2020; Zavadskas et al., 2024).

2.3.1. Analytic Hierarchy Process (AHP)

AHP was employed to derive the relative weights of the nine criteria. Pairwise comparisons were gathered from 71 experts (using Saaty's 1-9 scale (Saaty, 1980)), aggregated using the geometric mean, and consistency-checked (CR = 0.08). Expert Choice software was utilized.

2.3.2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS was utilized to rank the 14 facade alternatives. The decision matrix integrated AHP weights with performance scores derived from expert ratings and supplementary quantitative data (e.g., energy simulation outputs, cost estimates). Standard TOPSIS calculations were performed using MS Excel.

2.4. Energy Simulation (Supporting Analysis)

Building energy simulations (Design Builder/EnergyPlus; PHPP) were conducted to provide objective, quantitative data for the 'Energy Consumption' criterion and to support cost-benefit analysis. A representative residential typology for Tabriz was modeled to compare baseline performance against an optimized case (aligned with Iranian National Building Regulations [NBR] Topic 19) and evaluate relative energy demands of different facade systems.

2.5. Data Analysis Tools

Software utilized included SPSS (descriptive statistics), Expert Choice (AHP), MS Excel (TOPSIS), Design Builder, and PHPP (Energy Simulation).

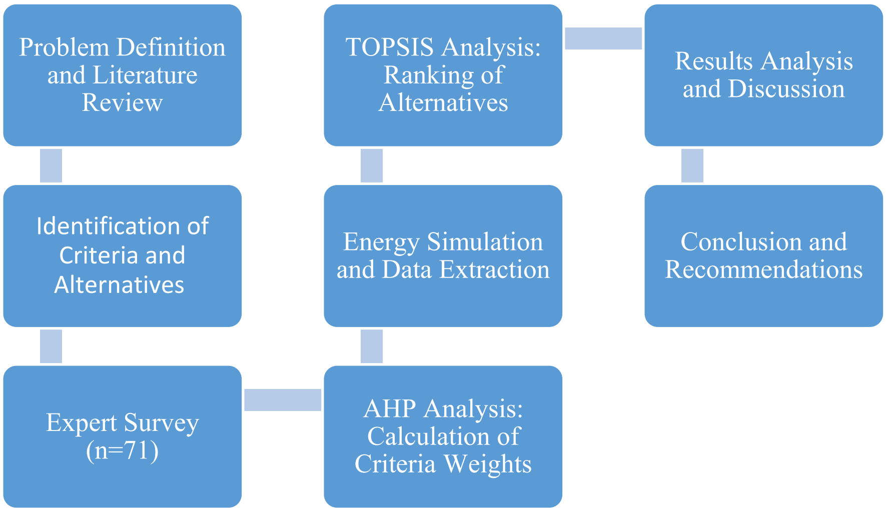

Fig. 1 Research methodology flowchart

3. Results and Discussion

The integrated analysis yielded pertinent insights into sustainable facade selection dynamics in Tabriz.

3.1. AHP Results: Criteria Weights

The results from the AHP analysis, which determine the final weights and relative importance of the nine facade evaluation criteria, are summarized in Table 1. As clearly shown in this table, local experts and stakeholders assigned the highest priority to 'Compatibility with Urban Architecture' (TM) with a relative weight of 0.186 and 'Aesthetics' (Z) with a weight of 0.177. This finding indicates the paramount importance of preserving the city's visual and cultural identity alongside the facade's appearance for the local community. Following these two, 'Environment/Sustainability' (MZ) with a weight of 0.156 and 'Maintenance' (TN) with a weight of 0.137 hold the next ranks of importance, reflecting attention to long-term performance and sustainability aspects. Conversely, criteria such as 'Implementation Time' (ZE) with a weight of 0.033 and 'Ease of Procurement/Execution' (ST) with a weight of 0.050 had the lowest importance from the participants' perspective. This weighting emphasizes that in the specific context of Tabriz, cultural-visual and long-term sustainability considerations take precedence over purely executional or initial cost (H with a weight of 0.094) factors.

Table 1. AHP Criteria Weights (Final values based on analysis)

Row	Criterion	Abbreviation	Final Weight
1	Compatibility with Urban Architecture	TM	0.186
2	Aesthetics	Z	0.177
3	Environment & Sustainable Dev. Principles	MZ	0.156
4	Maintenance	TN	0.137
5	Energy Consumption	ME	0.104
6	Cost	H	0.094
7	Technical Ability & Contractor Exp.	TP	0.062
8	Ease of Procurement & Execution Method	ST	0.05
9	Implementation Time	ZE	0.033

3.2. TOPSIS Results: Facade Option Ranking

Table 2 presents the final ranking results for the 14 facade alternatives using the TOPSIS method based on the criteria weighted by AHP (shown in Table 1). This ranking is also depicted graphically in Fig. 2 to facilitate visual comparison of the scores. The results (clearly observable in both Table 2 and Fig. 2) indicate that 'Smart Facade' with the highest CLi value (0.8872) was identified as the most preferable and optimal option for Tabriz conditions (considering all criteria). Following that, 'Green Facade' ranked second with CLi=0.7945. These high rankings demonstrate the superior overall performance of these two innovative systems across the multiple evaluated criteria. In the subsequent ranks, stone-based systems (composite with CLi=0.668, artificial with CLi=0.6541, natural with CLi=0.5823) and brick (CLi=0.5756) were placed, indicating the relative acceptability of traditional and common materials in the region. At the bottom end of the spectrum, as specified in Table 2 and Fig. 2, 'Standard Cement Render' ranked as the least desirable option within this evaluation framework with the lowest CLi value (0.175).

Table 2. TOPSIS Final Ranking and Relative Closeness (CLi) Values

Rank	Facade Alternative	CLi Value
1	Smart Facade	0.8872
2	Green Facade	0.7945
3	Natural Stone Composite	0.668
4	Artificial Stone	0.6541
5	Natural Stone	0.5823
6	Brick	0.5756
7	Aluminum Composite Panel	0.5217
8	Bayramix	0.5217
9	Timber Cladding	0.5207
10	Glass Curtain Wall	0.5203
11	Monolith Cement Render	0.4667
12	Ceramic Tile	0.4239
13	Expanded Metal Mesh	0.3564
14	Standard Cement Render	0.175

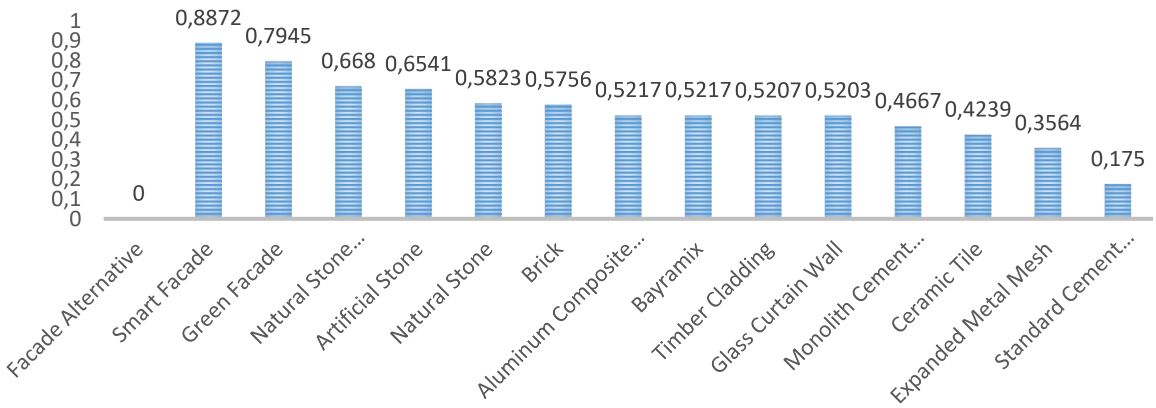

Fig. 2 Final ranking of facade alternatives based on TOPSIS (CLi) scores

3.3. Energy Simulation and Cost-Benefit Insights

To quantitatively investigate one of the key criteria, 'Energy Consumption', and also to support the cost-benefit analysis, energy simulations were performed. Table 3 presents the comparative results of annual energy consumption (disaggregated into heating and cooling, then summed) for selected facade types under Tabriz climatic conditions. This comparison is also graphically illustrated in Fig. 3. These results clearly show a very significant difference in the energy performance of various facades. As seen in Table 3 and Fig. 3, 'Smart Facade' (total annual consumption 50 kWh/m²) and 'Green Facade' (60 kWh/m²) exhibited the lowest predicted energy consumption, confirming their excellent performance in energy optimization. Conversely, common options like 'Glass Facade' (210 kWh/m²/year) and 'Standard Cement Render' (150 kWh/m²/year) (whose stark difference is also evident in Fig. 3) show considerably higher energy consumption, highlighting the need to move towards more efficient alternatives. These simulation findings strongly support the high ranking of smart and green facades in the TOPSIS analysis from an energy performance perspective. In addition to the comparison between facades, simulation results indicated significant energy saving potential (approx. 30 GJ/year) through basic facade upgrades (insulation, better glazing, shading) compared to a baseline case without these measures. The preliminary cost-benefit analysis based on these savings (using 2019 cost data) suggested an approximate five-year payback period for investments in these energy efficiency measures, indicating the favorable medium-term economic justification for such upgrades.

Table 3. Comparative Simulated Energy Consumption by Facade Type (kWh/m².year)

Facade Type	**Heating Energy (kWh/m².year)**	**Cooling Energy (kWh/m².year)**	**Total Energy (kWh/m².year)**
Smart (Adaptive) Facade	35	15	50
Green Facade	40	20	60
Double Skin Facade	45	25	70
Timber Cladding	60	40	100
Composite Panel	65	45	110
Stone Facade	70	50	120
Brick Facade	75	55	130
Cement Facade	85	65	150
Glass Facade	120	90	210

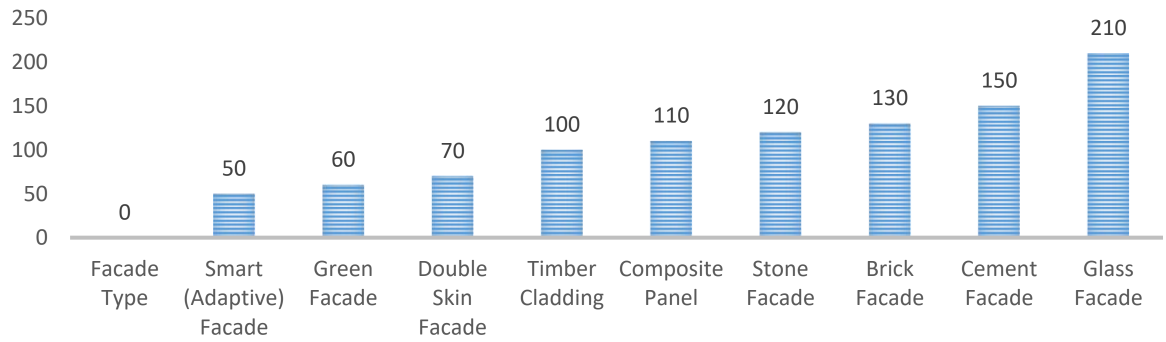

Fig. 3 Comparative total annual energy consumption for different facade types in Tabriz climate

3.4. Discussion

The study findings strongly advocate for adopting a holistic, context-sensitive strategy for sustainable facade selection in Tabriz. The superior ranking of smart and green facades aligns with international findings on their capacity for enhanced energy performance and broader environmental advantages (Favoino et al., 2020; Jim, 2021). The adaptability of smart facades allows for optimized responses to varying conditions (Tabadkani et al., 2021), while green facades offer valuable passive cooling and ecological benefits (Hopkins et al., 2022). Their top ranking confirms their potential suitability for Tabriz, contingent on addressing specific implementation and maintenance factors locally.

A key finding contributing to the novelty of this study is the pronounced importance assigned to 'Compatibility with Urban Architecture' and 'Aesthetics' by Tabriz stakeholders. This provides novel insight into regional priorities, potentially diverging from purely techno-economic or globally standardized environmental assessments (e.g., focusing solely on metrics like embodied carbon; cf. Pomponi & Moncaster, 2018; Shafiee et al., 2022). It highlights that sustainable solutions in culturally rich contexts like Tabriz must integrate socio-cultural values alongside technical performance. The economic analysis, while preliminary, supports the financial feasibility of adopting higher-performance facades (cf. Islam et al., 2019 on LCCA). The methodological contribution lies in the successful integration of subjective local priorities (via AHP) with objective performance data (simulations informing TOPSIS), creating a balanced and robust decision-support framework specifically validated for the Tabriz residential context.

4. Conclusions

This research successfully developed, applied, and validated an integrated MCDM framework (AHP-TOPSIS) coupled with energy simulation to optimize sustainable facade selection for residential buildings in Tabriz. It offers a structured, context-sensitive methodology that systematically balances diverse criteria reflecting local conditions and stakeholder values.

Key conclusions are:

- Tabriz stakeholders prioritize contextual compatibility and aesthetics alongside environmental performance and maintenance in residential facade selection.
- Smart (adaptive) and green facade systems emerge as the most advantageous solutions overall for Tabriz, based on a multi-criteria assessment incorporating local priorities and simulated performance.
- Investments in energy-efficient facade systems demonstrate economic viability within an approximate 5-year payback period, supporting their adoption.

This study's principal contribution lies in delivering a validated, context-specific MCDM framework for sustainable facade selection in Tabriz, uniquely integrating quantitatively assessed local stakeholder priorities with technical and environmental performance metrics. This provides a significant advancement over generic or purely technical assessments for this specific regional context. The findings offer practical, evidence-based guidance for stakeholders. Limitations include reliance on expert judgment and scope constraints. Future research should prioritize detailed Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) for the top-ranked systems, investigate locally adapted, cost-effective smart/green facade prototypes suitable for Tabriz's climate and construction practices, and potentially integrate post-occupancy evaluation feedback into the framework.

Acknowledgments

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Between mega-structures: The spatial-temporal memory of Bomontiada

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Abstract. Globalisation has accelerated production and consumption dynamics in Istanbul, driving spatial transformations, constant demolition, and the infill of urban voids. These rapid changes reduce the time individuals spend experiencing urban spaces, fragmenting spatial perception and preventing the full registration of transformation processes in memory. Consequently, a phenomenon of "forgetting" emerges. The discontinuity of memory spaces weakens spatial memory, deepening this condition. This paper examines the notion of "forgetting" within the context of global capital's large-scale urban projects, focusing on the Beyoğlu-Bomontiada industrial heritage site as a space resisting the temporal pressures of transformation. Through on-site analysis, the physical, functional, and socio-spatial structures of Bomontiada will be examined to visualise the impact of its transformations on spatial and temporal perception. The conversion of the historic brewery and its surrounding structures, along with shifts in temporal perception, will be documented through qualitative content analysis. The various manifestations of "forgetting" observed in the site will be analysed in relation to their effects on collective memory and spatial outcomes. The study will employ written, visual, and digital sources, including reports, official documents, newspapers, archival records, news websites, and social media databases. The findings will contribute to a deeper understanding of the interaction between urban interventions and memory spaces, offering insights into strategies for safeguarding spatial memory in future urban developments.

Keywords: Memory, Bomontiada, Places of Memory, Globalizing Istanbul, Forgetting

1. Introduction

The Bomonti district is one of the central, lively, cosmopolitan and oldest districts of Istanbul. It is a region that has undergone transformation through the city's cultural and artistic industries. It has significant importance as one of the most important private factory initiatives in Türkiye's economic history. The name Bomonti comes from the Bomonti Beer Factory, founded by the Bomonti brothers in 1890. It was named after the Bomonti Beer Factory, and also earned the nickname "Chocolate Scented Neighborhood" due to the Nestlé factory (Toprak & Hacihasanoglu, 2025). Bomonti has undergone significant changes driven by political policies, economic and spatial interventions from past to present.

Globalization is a comprehensive transformation process characterized by the acceleration of social, cultural and economic interactions. The acceleration of globalization and urbanization processes profoundly reshapes the social, economic and spatial structures of contemporary cities. In large metropolises like Istanbul, this transformation leads to the intensification of production and consumption dynamics, the continuous restructuring of urban space and the reuse of urban spaces with new functions. This intense and ongoing change affects not only the physical environment but also the way individuals relate to the city and the formation of urban collective memory.

The distinguishing feature of collective memory is its repetitive dynamic structure that forms within the ordinariness of daily life and maintains a sense of continuity with the past (Halbwachs, 2020), (Çolpan, 2017). This dynamic structure reveals that collective memory is not static, but rather a constantly reshaped process affected by changing social conditions. Today's city dwellers tend to establish shorter and more superficial relationships with places due to the acceleration of life and spatial discontinuities, which reduces the possibility of these places settling in memory. In the context of temporal compression and shallow experiences, both individual and collective memory have difficulty establishing a connection with urban space, which leads to the disruption of memory formation. In cities like Istanbul, which are open to constant change and intervention, this phenomenon weakens the continuity of memory spaces and triggers a collective state of 'forgetting' at the urban scale.

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Capital-driven large-scale projects and megastructures often erase the existing urban fabric and integrate new functions, architectural typologies and perceptions of time into urban life. This transformation sometimes clashes with historical layers, sometimes makes them invisible and erases the traces of the past. Bomontiada, located in the Bomonti district of Şişli, Istanbul, is a strong example in this context. The transformation of the old Bomonti Beer Factory, once a symbol of industrial production, into a cultural complex has led to a significant change in both its functional and socio-spatial context, despite preserving its physical structure. This study aims to examine the effects of urban transformation on the relationship between place, time and memory through the example of Bomontiada. By investigating the 'states of forgetting' observed during the transformation of the area, it will analyze the existence of industrial memory from the past in the new context surrounded by contemporary megastructures. In this context, qualitative content analysis based on visual and digital sources will be used to reveal the effects of spatial discontinuities in the city on collective memory. The research aims to develop a critical perspective on how spatial memory can be reconstructed or preserved within the rapidly changing urban structure of Istanbul and to contribute to a broader discussion on the relationship between memory, space and time.

2. Conceptual Framework: The Concepts of Memory and Forgetting

2.1. Memory

The concept of memory has been the subject of many thoughts and studies since ancient times. Memory is individual, but it cannot exist independently of society. It is the mental space in which a person preserves all the conditions, images, and information experienced throughout their life by passing them through the perceptual filter of their senses (Bartoletti, 2011). Memory, the most important tool for carrying the traces of the past into the present, is one of the key factors that both shapes and influences individual and collective consciousness (Orianne & Eustache, 2023). Memory is not a simple record of the past, it is a reconstructive process that continues in the present as a dual operation of the past (Cubitt, 2013).

Memory is defined not merely as a neurological function, but as a sociological concept. Like emotions, memory is a phenomenon that can be experienced and is influenced by its surroundings. It can be seen as a reflection of personal, cultural, psychological, neurological, political, religious, social, and ethical influences. The understanding of time resulting from a person's inner experience and life's encounters forms memory. Since memory involves the evocation of past perceptions that resemble everyday perception, selecting images and impressions from them, it can be said that memory has the characteristic of being shaped by experiences within the ongoing flow of the present (Zafer, 2019).

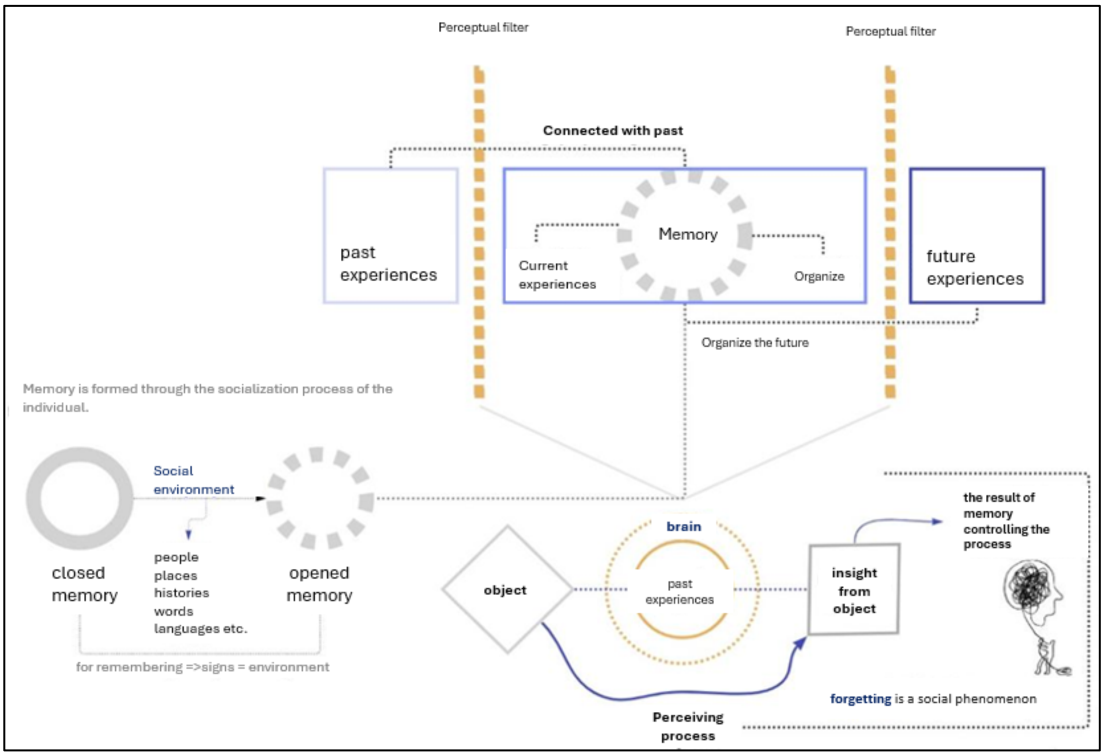

Fig. 1. Functioning of memory diagram

The concept of collective memory emerges from the influence of society on individual memory. Individual memory is not separate from society and its shared memory. In the broadest sense, collective memory refers to the memories shaped by the societies and cultures in which individuals live (Whitehead & Rossington, 2007). Collective memory is an image of the past and allows the group to recognize itself through a series of collective images (Hutton, 1988). Society and environment are the key actors in the formation of memory. Based on the connection of the memory concept with the past, it would not be wrong to say that collective memory is also connected to the past of society. In this case, the memory that emerges consists of the shared memories of society (Wertsch, 2009). In this way, the concept of collective memory is defined by its mediating role between individuals who make up society and across different periods of time. It has been stated that collective memory has a dimension that can reach individuals through the life experiences of a person and their contemporaries. Based on this, it can be said that the concept of collective memory also involves the collective retrieval of the past through remembering and its disappearance through forgetting. Through Remembering/Forgetting, collective memory continues its existence by constantly redefining and producing itself. Fig. 1 shows the functioning of memory.

2.2. Memory- Time- Place Relationship

The concepts of collective memory and place are closely connected. While memory originates from individual experiences, it becomes collective through sharing in public places. The actors who construct collective memory encounter and interact within physical place. The actors hold a spatial dimension because they shape the social reality of the present moment and represent the past by externalizing it once again (Kansteiner, 2002). Fig. 2 presents the connection between memory, place, and experience.

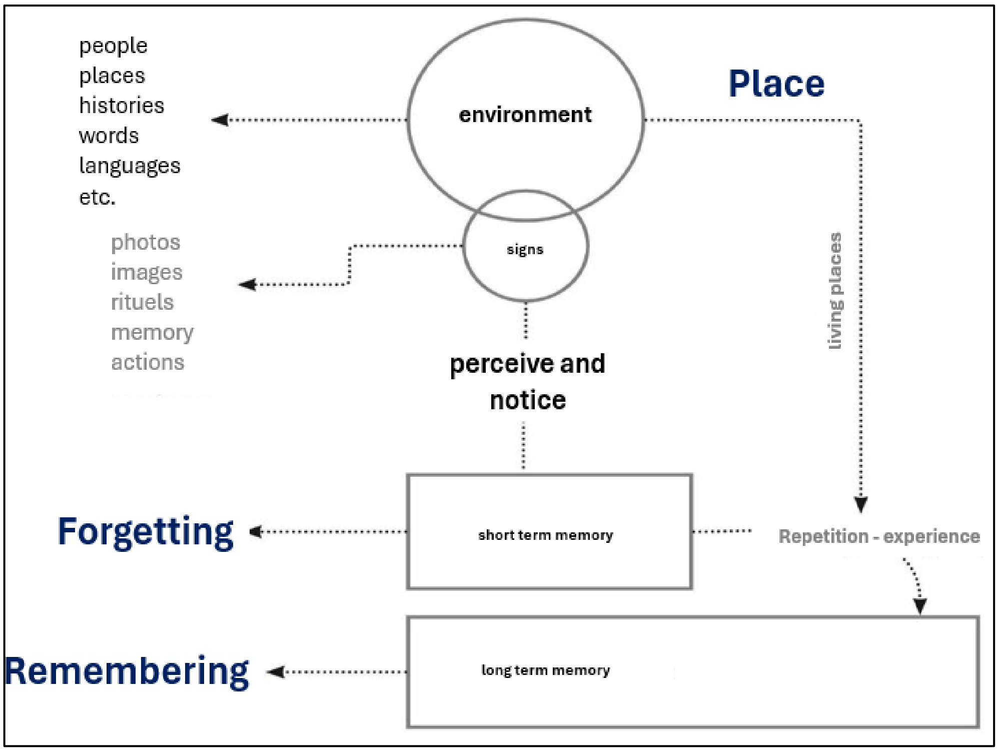

Fig. 2. Memory-Place-Experience diagram

Similar to memory, space acquires significance through lived experience. Architectural structures are socially constructed and reinterpreted through the ways they are experienced by individuals and communities (Lefebvre, 1991, 2014). When buildings are socially experienced, they are continuously reinterpreted and reproduced. For a space to become a "place," it must be nourished over time by memories. This makes memory and space inseparable concepts. Collective memory depends on space, and this relationship is clearly observable. As the concept of speed enters the equation, the boundaries of time expand, perceptions shift, and the interactions that shape memory begin to transform. In this process, the phenomenon of forgetting becomes more prominent.

3. States of forgetting in Bomontiada and its surroundings

The act of forgetting occurs as a result of insufficient time being dedicated to the historical layers and experiences of the city and its inhabitants. Several factors contribute to the act of forgetting. Urban policies, interventions in urban space, technology, transformations in human life, metropolitan living, transportation, socio-cultural conditions, and habits all influence the passage of time, and in turn, the speed at which it changes. This speed alters our perception of time and space. Due to the variety of factors that affect speed, there are also various forms of forgetting. We typically read the history of the city within a previously established framework; however, as identities shift, this situation manifests as urban or historical amnesia, or memory loss. Amnesia occurs involuntarily and refers to individual forgetting, while societal forgetting is a dimension that can be organized (Kankal, Akpınar, Kömürcü & Özşahin, 2011). The situation described in Akpınar's definition refers to the displacement of identities in line with urban political policies, as well as the destruction, transformation, and changes that occur in order to control urban life or guide city dwellers. These actions may lead to organized amnesia, or forgetting, resulting from such interventions. Fig. 3 shows the contexts in which states of forgetting emerge.

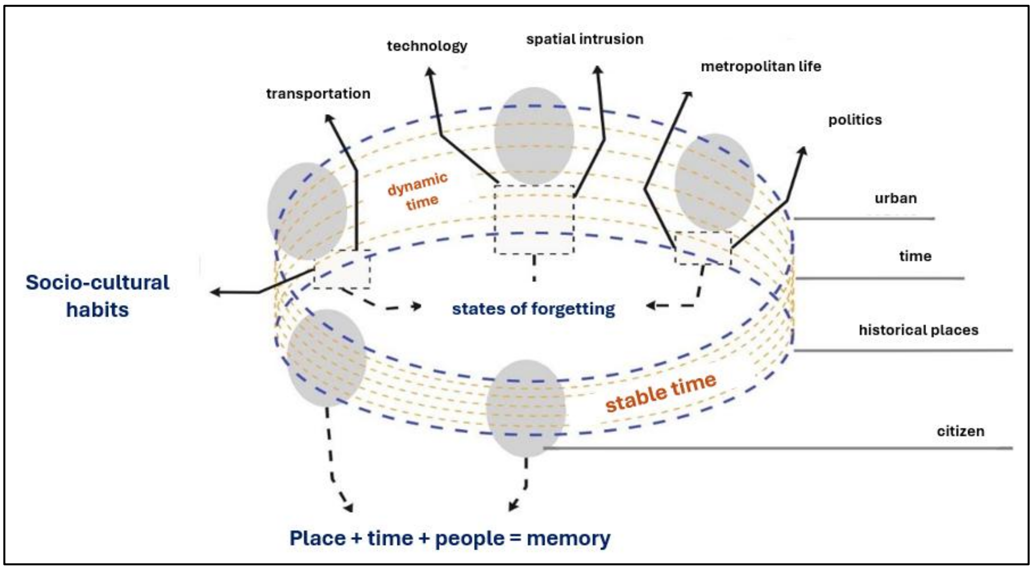

Fig. 3. The gaps in which states of forgetting

In 1890, Bomonti was a rural area on the outskirts of Istanbul. With the industrialization policies of the Ottoman Empire, along with the Brewery, industrial buildings increased, and this area became an industrial zone (Kaya & Arıkan, 2009). Although it continued as an industrial zone until the 2000s, with the influence of neoliberal policies and the privatization initiatives that began in Turkey, factories closed or moved to the city's new outskirts. As a result of this transformation, the industrial area changed into residential and commercial spaces. Due to its location and the vast empty spaces created after the relocation of factories, the area became highly valuable for urban transformation. The value of the land, particularly for new housing, is significant. One of the vacant spaces is the Bomonti Brewery itself. Although it was placed under protection in 1998, it remains an excellent location for urban transformation. Therefore, in 2010, the brewery area underwent a restoration process as part of a cultural transformation project and began operations in 2015 under the name Bomontiada, functioning as a hotel, entertainment, and cultural center (Mert-Travlos, 2021).

The Bomonti neighborhood, with its transformations and changes, is a site rich in layers of collective memory, where each layer is still visible and can be read alongside new layers. This makes it a valuable area for memory studies. Its location is also easily accessible and offers a safe environment for its users. With all these characteristics, it has been chosen as our study area. The research problem addresses the act of forgetting, which will be analyzed within the context of Bomontiada, aiming to identify the states of forgetting. Bomontiada, being a continuously evolving space both functionally, socio-culturally, and spatially, contains multiple aspects of forgetting. To identify the states of forgetting in Bomontiada and its surroundings, key breaking points throughout its history have been mapped and analyzed, as shown in Fig. 4a and 4b. Referring to our diagram of the states of forgetting, it has been determined that the act of forgetting in Bomontiada and its surroundings is shaped by political policies, demographic changes, and spatial interventions, as depicted in the Fig..

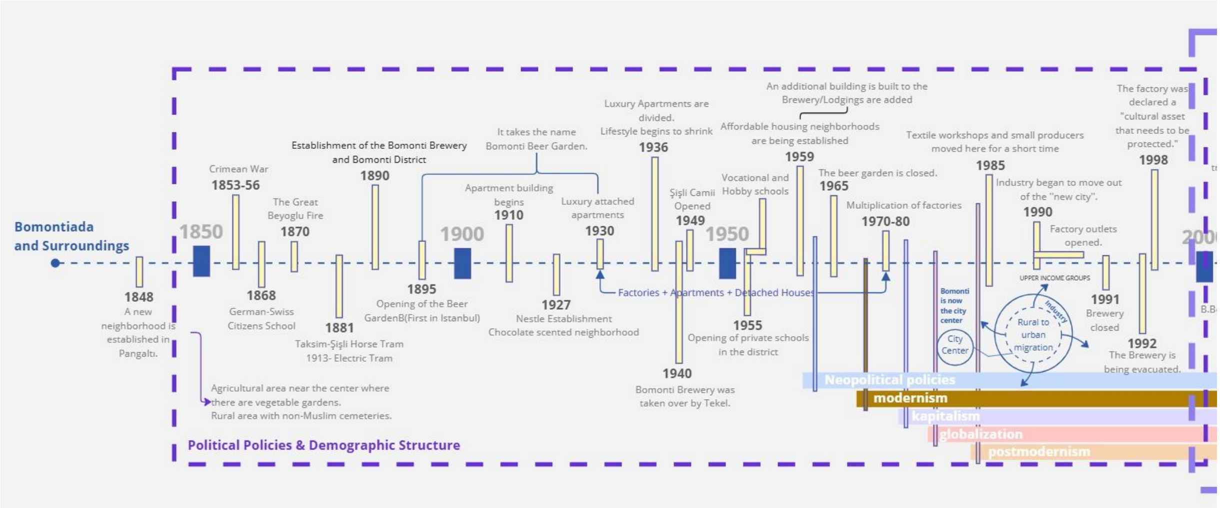

Fig. 4a. Breaking Points in history for Bomontiada and its surroundings

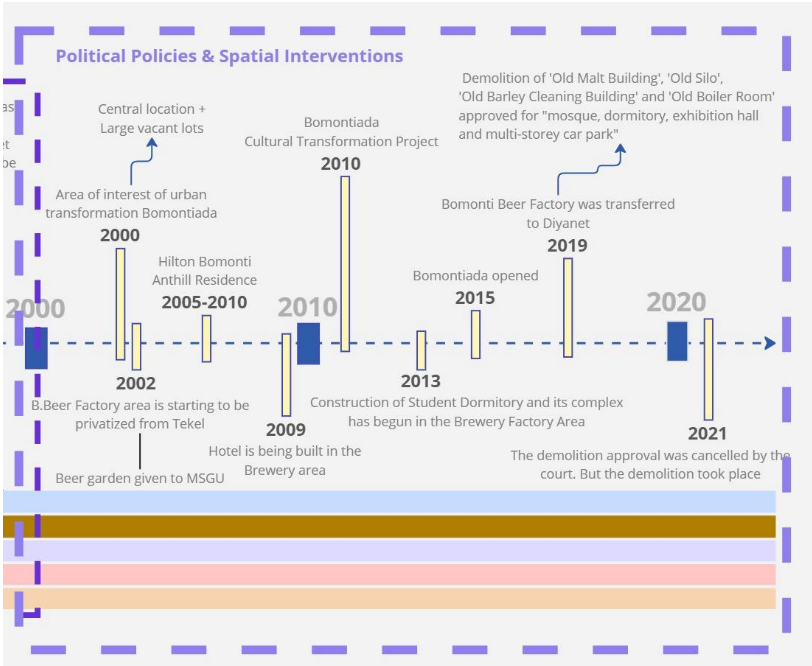

Fig. 4b. Breaking Points in history for Bomontiada and its surroundings

3.1. States of Political Policies and Demographic Structure

3.1.1. 1850-1950 Industrialization Period

Thanks to the industrialization policies of the Ottoman Empire in the second half of the 19th century, the Bomonti brothers obtained a concession to open a factory in Istanbul (Çelik, 1993). The establishment of the Bomonti Brewery is directly linked to these industrialization policies (Kaya & Arıkan, 2009) The policies played a key role in the creation and identity of the Bomonti neighborhood. Following the Crimean War (1853-1856), many foreigners settled in Istanbul, especially in the rural outskirts like Bomonti. Bomonti was established by Levantines, and evidence of this can be seen in the non-Muslim cemeteries in the area. The Bomonti Brewery opened in 1891 as a Brewery and Nectar Factory (Keyder & Quataert, 1994). A new way of life based on production was adopted, and the area became both an industrial hub and a multicultural neighborhood. Socio-economic diversity and a strong sense of belonging based on production were prominent. As industrialization spread across Turkey, a large migration from rural areas to Istanbul took place. Bomonti became an attractive destination for the new working class. Neighborhood culture, solidarity, and class unity grew stronger (Özden, 2024). In 1926, a state alcohol monopoly was introduced, and the Bomonti Brewery continued operations under a

Turkish-Joint Stock partnership. In 1938, the factory was closed for two years, and in 1940, Tekel took full control. Fig. 5 shows key events from this period.

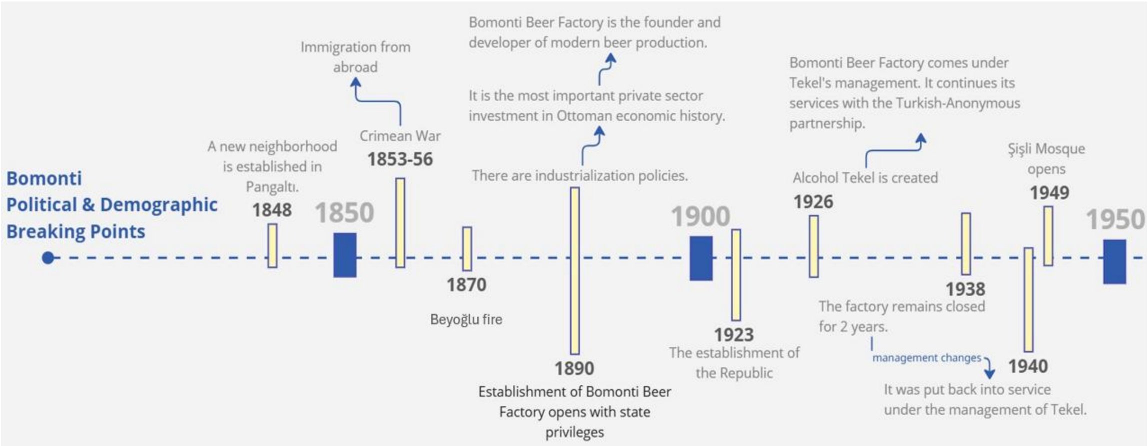

Fig. 5. 1850-1950 Political and demographic breakthroughs

3.1.2. 1950-2000 Neoliberal Policies and Deindustrialization

Until the 1980 coup, Bomonti remained an industrial area, but after the coup, neoliberal policies began to take hold and their impact increased (Mert-Travlos, 2021). In 1984, deindustrialization policies were adopted, and major institutions became dysfunctional. Turkey experienced an economic crisis, and the Bomonti Brewery closed in 1992. With the growing influence of neoliberal policies and the decline of industry, job losses began to rise (Şenses, 2012). The buildings became old and neglected, rents increased, and the neighborhood culture started to weaken. This period is marked by economic decline and spatial degradation. However, despite all these changes, Bomonti has continued to be a preferred neighborhood due to its proximity to central locations, safe community environment, and cultural activities. Fig. 6 shows the key events that occurred during this period.

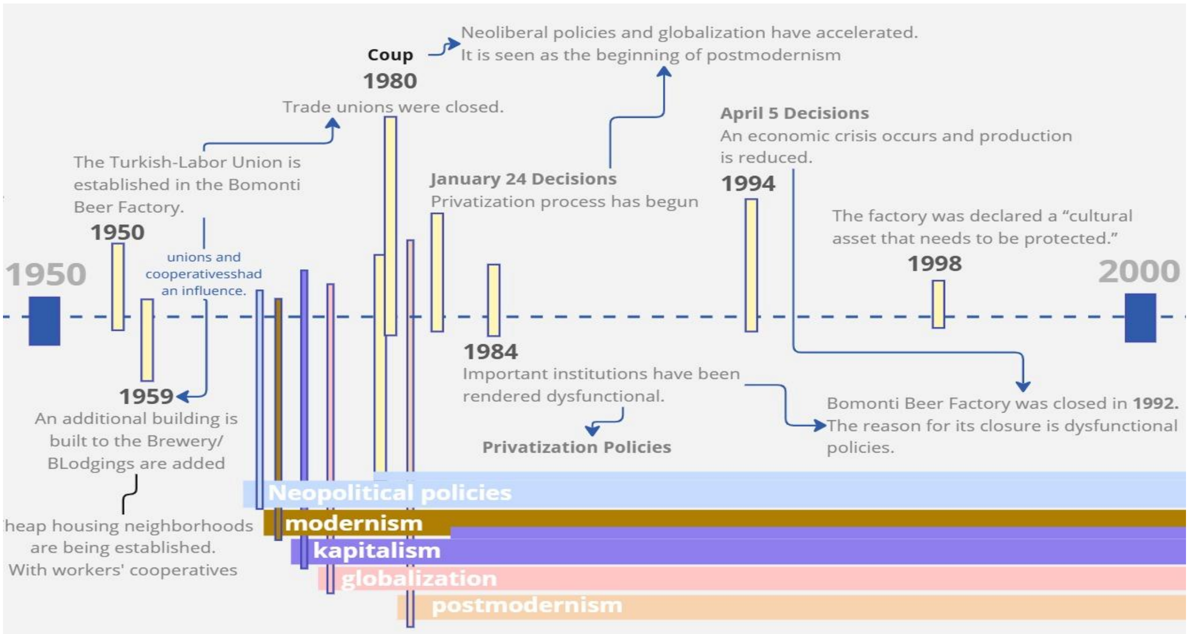

Fig. 6. 1950-2000 Political and demographic breakthroughs

3.1.3. 2000-2025 Gentrification and Globalization

After the 2001 economic crisis, the impact of globalization began to grow in Turkey. Urban transformation projects started, and the Bomonti area began to increase in value. The factories became a significant opportunity for gentrification and urban renewal (Guven, 2017). Old working-class families have been replaced by young professionals and investors, marking the first strong wave of gentrification in the area (Paton, 2016). By 2015, with the opening of Bomontiada and the surrounding hotel and residential projects, Bomonti transformed into a global investment hub. The neighborhood now hosts: foreign residents (especially individuals from creative industries), high-income professionals, and short-term rental groups for tourism purposes (Garay-Tamajón, Lladós-Masllorens, Meseguer-Artola, & Morales-Pérez, 2022). The area has transformed from a production zone into a consumption zone. This change has led to shifts in spatial practices and user identities, ultimately resulting in the disruption of urban memory. Fig. 7 illustrates the key events that occurred during this period.

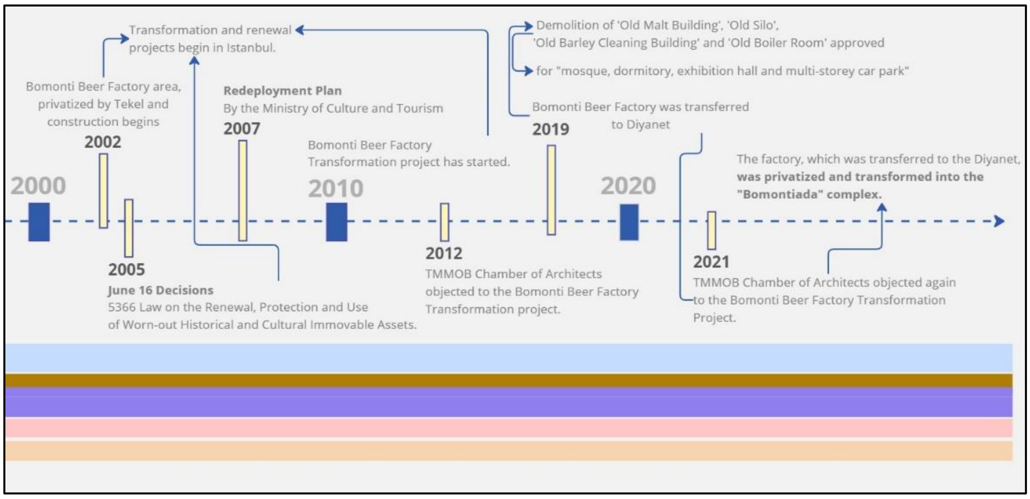

Fig. 7. 2000-2025 Political and demographic breakthroughs

3.2. Spatial transformation analyses in Bomontiada and its surrounding

3.2.1. Spatial Intervention
Space is not only a physical entity but also a carrier of social relations, everyday life practices, and collective memory (Lefebvre, 1991, 2014). However, when interventions in space, especially those driven by global capitalist dynamics and large-scale developments, occur, this carrier function can be disrupted (Harvey, 2008). The Bomonti neighborhood in Istanbul provides a characteristic example of this process. Historically associated with industrial production and neighborhood culture, Bomonti has undergone significant transformation in the last thirty years due to spatial interventions, leaving permanent marks on urban memory. This urban transformation is shown in Fig. 8.

Fig. 8. The spatial condition resulting from urban transformation. (IBB 3D City Planning website, Kovanlıkaya, Ç., Fırat, D., Yılgür, E., Aslan, Ş., & Özarslan, A. D. (2021)).

This transformation process has not only involved the reorganization of the physical environment but also weakened the emotional and historical connections that urban dwellers have with the space. The disruption of spatial continuity interrupts the experiences accumulated over time, causing perceptions of the past to blur and the memory of the place to fade. As a result, the relationship between time and space becomes superficial, and the space transforms into something "forgotten" rather than "reminiscent." (Boyarin, 1994). In the case of

Bomontiada, the transformation of places bearing traces of industrial heritage into cultural consumption spaces leads to the suppression of historical context and the gradual weakening of the collective memory of the place. As a result of this transformation, the continuity of urban memory is disrupted, and the meaning of the place becomes detached from its historical context. Another example is the Bomonti Brewery Garden, located adjacent to the Bomonti Brewery, a space where workers and neighborhood residents socialized and integrated into daily life (Turhan, 2018). This area has since been transformed into a cultural heritage site and is now used as a university building, currently home to Mimar Sinan University. The space has ceased to be a public area, and one of Bomonti's most significant social memory sites has vanished. As it is now used as an educational building, the most important memory space of the Bomonti district has been forgotten. Fig. 9 shows the Bomonti Brewery Garden past and present.

Fig. 9. Bomonti Brewery Garden Transformation (Kovanlıkaya, Ç., Fırat, D., Yılgür, E., Aslan, Ş., & Özarslan, A. D. (2021) , Google Search).

3.2.2. Construction in Bomontiada and its surrounding

The first traces of construction in the Bomonti area began to emerge in the 1860s with the establishment of the Bomonti Brothers' beer factory. This industrial structure became not only an economic production site but also a place where working-class neighborhoods were formed (Bellamy, 2019).

By the 1920s, the residential fabric, religious buildings, educational institutions, and small-scale commercial units that developed around the area allowed Bomonti to create a unique collective memory. The construction during this period strengthened the spatial identity and created reference points that became embedded in the memory of the city's inhabitants (Boyer, 1994). In the early 2000s, the privatization and sale of public lands disrupted the spatial continuity of Bomonti for the second time (Keyder, 2005). The transfer of the Bomonti Factory land to private investors weakened the representation of production areas within collective memory and caused the space to lose its sense of being "public."

In the 2010s, the Bomontiada project, which transformed the old factory structure into a cultural, artistic, and entertainment space, led to a third transformation in the identity of the place. While the cultural use may appear to claim "memory preservation" on the surface, the representation of the space's production history has, in fact, been reduced to a mere stage set (Erdoğan, 2013). The production history has been reconstructed within the framework of consumption-driven activities and the experience economy. At the same time, the construction of mega structures such as the Hilton Bomonti Hotel, Anthill Residences, and Spine Tower around the Bomonti area has dramatically changed the spatial scale of the neighborhood (Shatkin, 2017).

These massive structures, which are incompatible with the neighborhood fabric, have caused both physical and perceptual scale disruptions. The horizontal continuity of everyday life has been replaced by a vertical and fragmented urban experience. After 2020, Bomontiada and its surroundings have become heavily commercialized and turned into a tourist destination (Zukin, 1995). Cultural activities have been replaced by consumption-focused festivals, and branded events. This process has further led to the erasure of local cultural practices and traces of 0everyday memory. Fig. 10 shows the map of construction from the past to the present.

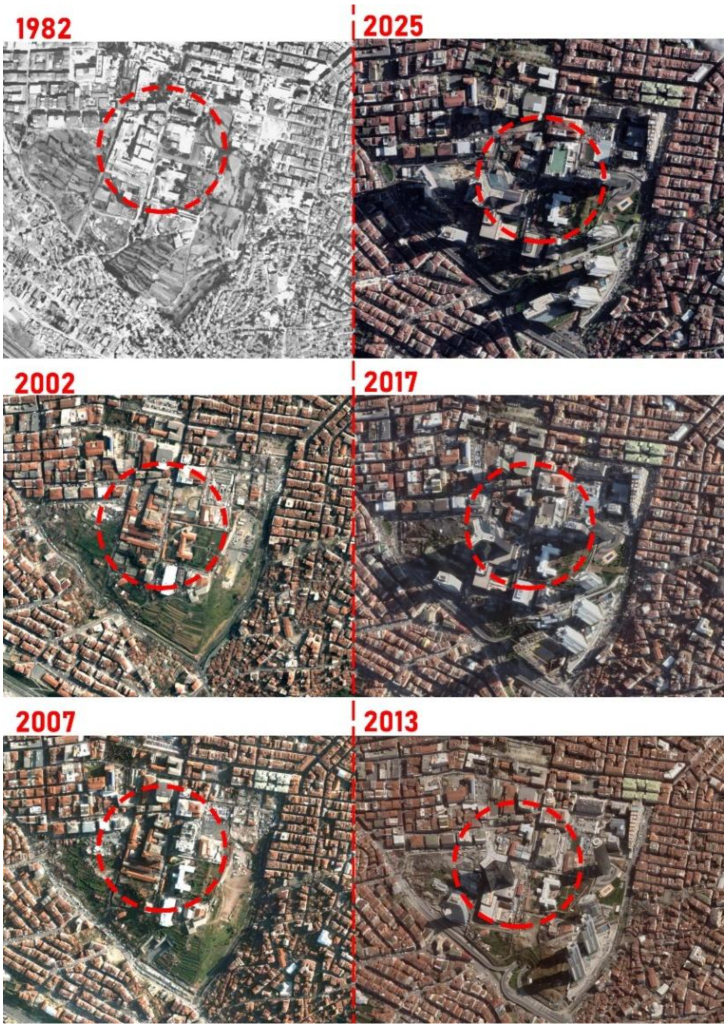

Fig. 10. Construction Maps from Past to Present (Google Maps).

As a result, the fragmentation of the neighborhood fabric has led to the loss of the multilayered meanings the space carried from the past to the present. The emergence of dysfunctional areas within the same street that cannot relate to each other has disrupted users' sense of continuity with the space. This transformation affects not only the physical environment but also the memory connections established with the space. While this transformation causes the region's cultural identity to be forgotten, it also weakens users' sense of spatial continuity and belonging.

4. Bomontiada Among Megastructures

Symbolic structures, one of the carrier elements of urban memory, are architectural and historical elements that form the identity of a place and add meaning to the collective experiences of city dwellers. Bomontiada, which has an industrial production center in Istanbul, has gained a strong place in urban collective memory with its ymbolic value. The old and new states of this symbolic structure are shown in Fig. 11 and Fig. 12.

Fig. 11. The Old and New Forms of Symbolic Structures (Kovanlıkaya, Fırat, Yılgür, Aslan & Özarslan, 2021)

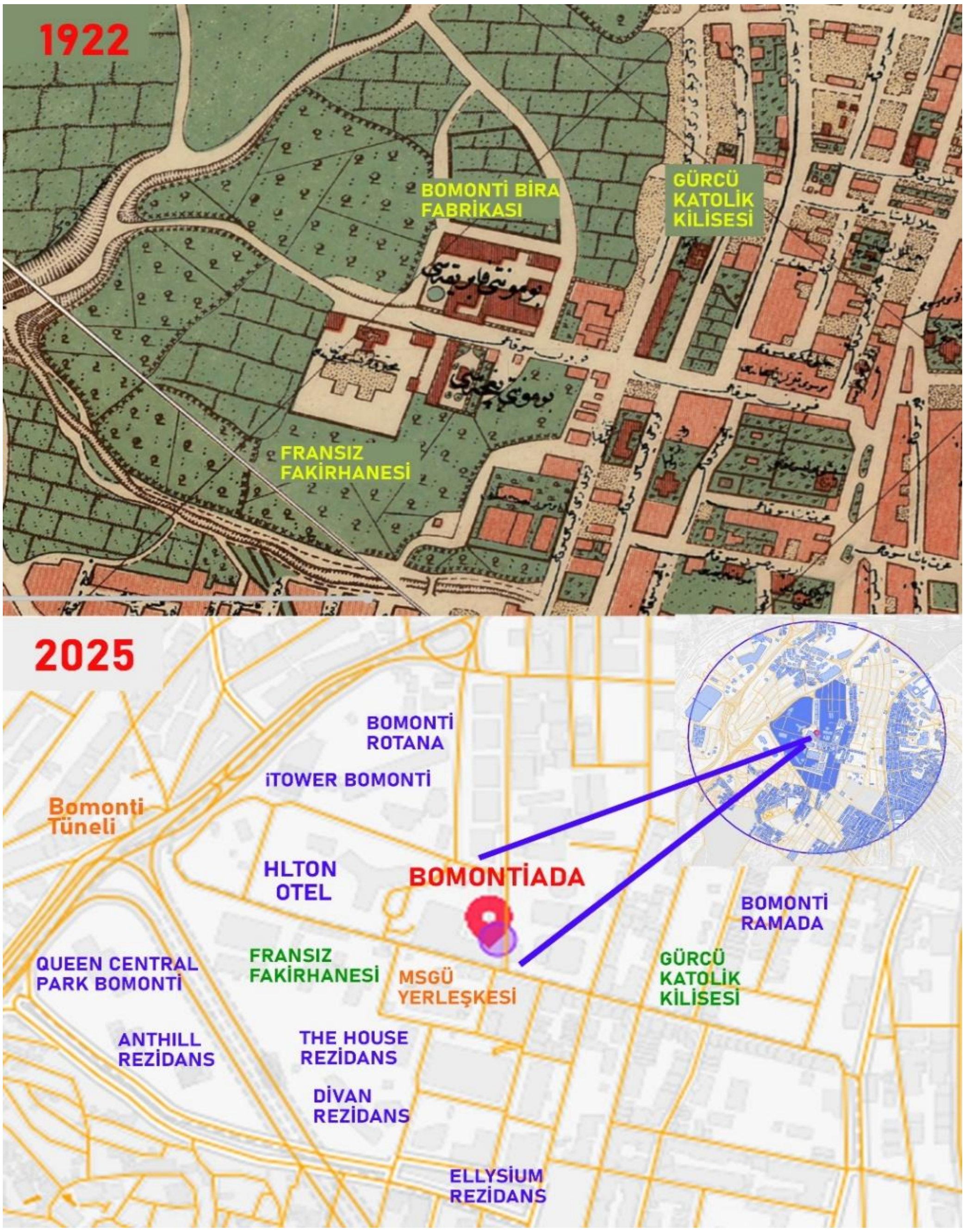

Fig. 12. Bomontiada and Its Construction (istanbulurbandatabase.com, Google Maps).

Although the physical appearance of the structure has been preserved, its content and historical context have faded into the background, and elements that nourish the memory of the space have largely disappeared. This is not merely a physical repurposing but also a transformation of historical and social meaning. An example of this is the significant disruption in the spatial and economic memory of the neighborhood when the Bomonti Beer Factory ceased its production function in the 1990s (Öncü, 2011). The closure of the factory not only created a physical void but also weakened the working-class culture in the neighborhood. This process led to the erasure of collective life practices based on production, and the first voids began to form in the spatial memory (Gürleyen, 2018). Changes that focus solely on the exterior of symbolic structures disrupt the continuity of urban memory, causing the meaning these structures carry in collective memory to become superficial. As a result, buildings that once represented the past lose their significance in the present through forgetfulness. As shown in Fig.s 12 and 13, Bomontiada and its surroundings have been filled with mega structures since the past.

Fig. 13. Bomontada’s Silhouette Changes Over Time (Quoted From Sanalarch.)

Fabrika, which was the focal point of its surroundings from the first years of its operation until its closure, continues to be a focal point with a different culture today. With the consumer culture and the accelerating understanding of life spread to the district by mega structures, the factory area has turned into an entertainment venue. The production culture has been erased from memory and has remained as a pleasant memory, replaced by the consumer culture. This is even reflected in the silhouette in Fig. 13.

4. Conclusion

The spatial changes of Bomontiada and its surroundings due to political reasons and spatial interventions from the past to the present were examined with qualitative research techniques. As a result of this examination supported by images, we can say that the concept of forgetting, which we consider as a problem, is visible at certain points, but it has not completely taken over Bomontiada.

First of all, when we look at the spatial transformation, which is one of the states of forgetting, we observe that the ease of transportation, which was important during the first period of Bomonti's establishment, continues. Especially today, with its proximity to the E-5 Highway and the construction of the Dolmabahçe-Bomonti Tunnel, access to Bomontiada has become quite easy. With this, it is still a very preferred district as it was in the past with its preservation of its vitality and job opportunities. It appeals to various user types with its education centers, luxury residences and food sector, and this actually ensures that it maintains its cosmopolitan neighborhood identity as it was in the past. On the other hand, luxury residences and apartments have transformed Bomontiada from its old focal point in terms of structure scale into a new place. It has become difficult to notice among mega structures, and due to the profiteering transformation, it has lost its additional buildings to these mega structures. Although the Bomonti Beer Factory is known by name thanks to the efficiency of the Ara Güler Museum and Restoration work, the old production culture is unfortunately not continued. In this case, the production culture has been forgotten from memory and has now remained as an entertainment center in the memories of new users. Another place of memory that is as important as the Beer Factory for Bomonti is the Beer Gardens. Unfortunately, this area has been sacrificed to profiteering transformation and its transformation has been carried out with a political subconscious. It has been completely removed from its public space nature and a building belonging to MSGÜ has been built in its place, but unfortunately, even the landscape of the building has not been designed as a public space. As a result of the examination of Bomontiada and its surroundings, the states of forgetting, its historical period and the effects of these states are shown as in Fig. 14.

	DEMOGRAPHIC STRUCTURE	SPATIAL FUNCTION	POLITICAL-ECONOMIC PROCESS	URBAN LIFE PRACTICES	MEMORY AND SOCIAL IMPACT
1850 1900	LEVANTINES, MINORITIES, NATIVE WORKERS	INDUSTRIAL AND PRODUCTION ZONE	INDUSTRIALIZATION POLICIES INCENTIVE PRODUCTION MULTICULTURAL URBANIZATION	PRODUCTION-BASED LIFE FACTORY-SPACE SOCIALIZATION STREET SHOPS STREET TOGETHERNESS	BASED ON PRODUCTION CULTURE NEIGHBORHOOD BELONGING WORKING CLASS MEMORY
1900 1950	WORKING CLASS OF ANATOLIAN ORIGIN, COMING BY INTERNAL MIGRATION	INDUSTRIAL + RESIDENTIAL AREA	INDUSTRIALIZATIONS INTERNAL MIGRATION WAVEASLUMS	GAMES ON THE STREET FAMILY-CENTERED LIFE SOLIDARITY NETWORKS	RURAL-URBAN HARMONYK SOCIAL SOLIDARITY NETWORKS
1950 2000	MIDDLE-LOWER CLASS FAMILIES, TENANTS	APARTMENTIZATION + DESINDUSTRIALIZATION	NEOLIBERAL POLICIES NON-INDUSTRIAL ORIENTATIONNPRIVATIZATION WAVE	UNEMPLOYMENTİSPATIAL ABANDONMENT SOCIAL DISSOLVMENT	DECREASE OF PRODUCTION MEMORY EMPTYING OF SPACE
2000 2015	PROFESSIONALS INVESTORS	LUXURY HOUSESL+ OFFICES + HOTELS	URBAN TRANSFORMATION AND GENTRIFICATION POLICIES	CONSTRUCTION INTENSITY RENTS AND LIVING PROBLEMS NEW NEIGHBORHOOD CONCEPT ALIENATION	CLASS CHANGE EROSION OF NEIGHBORHOOD IDENTITY
2015 2025	HIGH INCOME GROUPS FOREIGN INVESTORSYCREATIVE CLASS	CULTURE-ART AND GASTRONOMY CENTER	GLOBAL CITY POLICIES CULTURAL CAPITAL PRODUCTION	CONSUMER-FOCUSED INDIVIDUALIZATION LOSS OF LOCAL IDENTITY DIVISION OF THE PAST	REPRESENTATION OF MEMORY CULTURAL COMMERCIALIZATION MEMORY GAPS

Fig. 14. States And Effects Of Forgetting For Bomontiada

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Evaluating the healthy city approach in the context of urban design competitions

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Abstract. Today, rapid and uncontrolled population growth along with increasing urbanization leads to serious environmental problems in cities. Unhealthy conditions emerging in physical spaces lead to the formation of unequal living spaces. This situation brings one of the fundamental goals of urban design, which is to create equal and fair living spaces for everyone, back to the forefront. The healthy city approach adopts an urban planning approach focused on equality in health and prioritizes considering different cultures and needs. In this context, it is important to evaluate how the healthy city approach finds a response in urban design projects. There are many prestigious competitions in Europe that increase the visibility of architecture and urban design and reward them. The projects that have won awards in recent years provide an important field of examination that shows how the healthy city approach aligns with its goals. Especially in the post-pandemic period, urban health and environmental issues have become the focus of competition projects. This study examines the last 5 projects that received awards in some prestigious competitions held in Europe such as the Veronica Rudge Green Prize and The European Prize for Urban Public Space within the framework of the concept of healthy city.The research was conducted on the credentials and explanatory reports of the award-winning projects; the relationship between urban design decisions and healthy city principles was comparatively assessed. It was determined that the award-winning projects mostly focused on themes such as accessibility of public spaces, environmental sustainability and promoting public health. While the Veronica Rudge Green Prize focuses on large-scale urban transformation and infrastructure projects, The European Prize for Urban Public Space touches on urban space with smaller-scale interventions. The projects reveal that the concept of healthy city is prioritized in topics such as increasing green areas, improving air quality, developing pedestrian-friendly spaces and promoting community participation. In addition, universal health goals such as ensuring social justice and resilience to climate change are among the prominent elements. This assessment highlights the critical role that award-winning projects play in creating healthy cities and the impact of urban design competitions in this process.

Keywords: Healthy city; Urban health; Sustainability; Competition projects; Community health

1. Introduction

Today, the urbanization process brings with it serious environmental and social problems due to rapidly growing population and uncontrolled development. Rapid urbanization destroys natural ecosystems, while unplanned growth and inadequate infrastructure create unhealthy living conditions. Especially with the increasing population, large cities are rapidly migrating, spatial inequalities are increasing, and low-income groups are mostly forced to live in unhealthy and low-quality living spaces. One of the primary goals of urban design, 'creating equal, sustainable and accessible healthy living spaces for everyone', is becoming even more important.

Urban design and planning approaches are in a state of transformation due to increasing population, developing technology, and global disasters, epidemics, and wars. This dynamic process directly affects the spatial organization and quality of life of cities. In this respect, approaches to sustainable, resilient and flexible urban design are becoming increasingly important. In this context, smart city technologies, ecological planning strategies, healthy city models and human-centered design principles have become essential components in contemporary urban planning processes. The developing interdisciplinary understanding requires that cities be considered not only as physical spaces but also as dynamic systems in which social, cultural and economic interactions take shape. Urban design and planning decisions are expected to have approaches that offer more holistic and future-oriented solutions.

The concept of urban design has developed various movements and urban planning approaches throughout history depending on social, economic, environmental and technological factors. The Bahçeşehir Movement,

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which emerged in the late 1800s, proposed a model that combined the advantages of rural and urban life against the unplanned urbanization brought by the industrial revolution, while the Beautiful City Movement, which emerged in the early 90s, developed regular and symmetrical plans that emphasized urban aesthetics. In the 1920s, with Modernism, urban approaches based on functionality and rationality, high-rise buildings and wide open spaces came to the fore. The New Urbanism approach (1960s) advocated pedestrianization and a more neighborhood-oriented design approach as a reaction to automobile-focused urbanization. Postmodernism (1970s) brought a more aesthetic, flexible and historical reference-emphasized approach against the strict rules of modernism. In the 1980s, the Healthy City Approach was initiated by the World Health Organization. This approach aimed to increase the physical, social and environmental well-being of cities. Later, ecology and sustainability concepts came to the forefront in both planning and design approaches. Sustainable Urban Design (1990s) focused on energy efficiency and ecological planning as a solution to environmental crises. Later, with the developing technology, the Smart City Approach (2000s) suggested the integration of digital technology into urban design and planning. The Green Capital Movement (2010s) pioneered sustainable urbanism projects that encouraged environmental policies. When we look at all of these movements, we can see that they are a response to the changing needs of cities.

The concept of healthy city aims to increase the physical, mental and social well-being of individuals and aims to create sustainable and livable urban environments (Başaran, 2007). This approach, which was developed under the leadership of the World Health Organization, aims to increase the quality of life of the society by adopting a health-focused perspective in urban planning (Barton et al., 2010). Healthy cities should be supported not only by health services but also by elements such as housing quality, transportation, green areas, social integration and environmental sustainability (Aydın, 2019). In this direction, interdisciplinary cooperation, community participation and environmental factors should be taken into account in urban planning (Belli, 2019). The Healthy Cities Association has been established in Turkey within the framework of this understanding and encourages the active participation of municipalities in the process (Başaran, 2007). The healthy city approach stands out as a strategy that aims to make cities more livable in terms of physical, social and environmental health. This approach, emphasized by the World Health Organization, places health, sustainability and social equality at the center of urban policies. Increasing green areas, creating pedestrian-friendly spaces, improving air quality and encouraging community participation are among the fundamental elements of healthy cities.

In order for cities to be healthy and livable, urban design must be shaped in accordance with these principles. At this point, international urban design competitions play an important role in encouraging innovative solutions that support healthy city principles. Prestigious architecture and urban design competitions in Europe increase awareness in this area by rewarding projects that support the healthy city vision.

This study aims to analyze how the healthy city approach is represented in prestigious urban design competitions in Europe. In particular, the study examines five recent projects that have won awards in international competitions such as the Veronica Rudge Green Prize for Urban Design and The European Prize for Urban Public Space. The spatial and environmental qualities of these projects are comparatively evaluated in the context of healthy city principles. By analyzing how urban health and environmental sustainability issues are addressed in the competitions, especially in the post-pandemic period, it is revealed how the award-winning projects contribute to the health-oriented transformation of urban space.

In this context, the main questions of the study are as follows:

- How are healthy city principles reflected in the award-winning projects?
- How do urban design competitions contribute to the development of healthy city policies?
- How do the award-winning projects address issues such as accessibility, environmental sustainability and public health?

Within the framework of these questions, the award-winning projects of the selected competitions within the scope of the research were analyzed through their explanatory reports and project descriptions, and how urban design is integrated with healthy city goals was evaluated. The findings emphasize the critical role that award-winning projects play in improving urban health and supporting sustainable city policies.

2. Healthy City Approach and Principles

According to the World Health Organization (WHO), a healthy city is a settlement area that offers a sustainable environment where individuals can maximize their physical, mental and social well-being and includes the entire society. WHO considers healthy cities not only in terms of preventing diseases but also in terms of creating urban policies and infrastructures that support healthy lifestyles (WHO, 1998). Healthy cities should be shaped based on basic elements such as clean water and air, adequate housing, effective transportation systems, accessible health services, social justice and social participation (WHO, 2010). In this context, a healthy city should be planned with a multidimensional approach that includes economic, social and cultural factors as well as the physical environment (WHO, 2021). Healthy urban planning is a dynamic process that aims to reduce social and physical inequalities in urban space. This process takes shape through experimentation, intervention, observation, learning and adaptation. It aims to strengthen social integration through urban design and planning, especially in areas where disadvantaged groups live, where spatial segregation is intense, and to continuously improve healthy living conditions for all city residents (Corburn, 2013). In this context, incorporating the principle of accessibility into urban planning not only ensures the removal of physical barriers but also helps to reduce the spatial impacts of social exclusion. In this way, it contributes to addressing inequalities within the city (Söylemez, 2021).

Healthy cities should be planned in line with the principles of sustainable environment, society and economy. The environmental dimension should protect the health of the physical environment and promote green areas, safe and inclusive spaces, and healthy housing. In the social dimension, consciousness and awareness should be increased, equality and inclusiveness should be ensured and solidarity between individuals and institutions should be strengthened. In terms of policies and services, participatory governance should be adopted, and basic urban services such as education, health, social services and transportation should be improved. This holistic approach aims to increase the quality of life of urban dwellers and support sustainable urban development (Gür, 2024). In this framework, the “Health Map for Local Human Settlements” developed by Barton and Grant (2006) offers a holistic model that conceptualizes the multi-layered structure of the healthy city approach. This model, where the individual is positioned at the center, visualizes the mutual interaction of many factors such as physical environment, lifestyle, social relations, access to services, economic structure and natural environment on health. The map is not only spatial planning; It also emphasizes that social policy, environmental sustainability and economic justice are directly related to health, and reveals the importance of interdisciplinary cooperation and long-term strategic approach in healthy urban planning. In this respect, the health map is a guiding tool in making cities more livable, inclusive and resilient. (Fig.1)

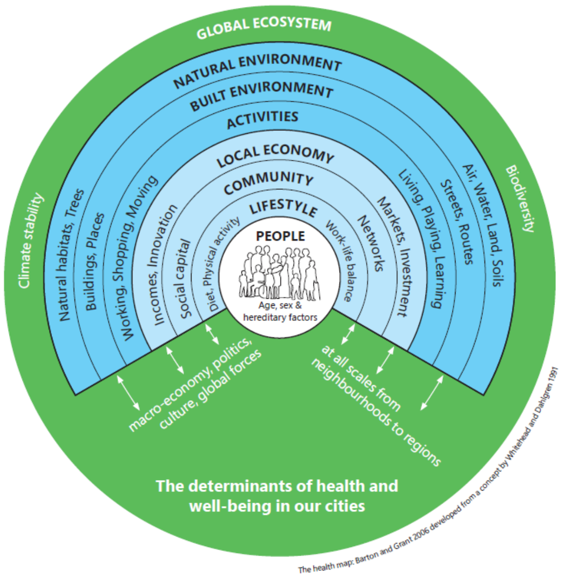

Fig.1. Conceptual Health Map for Healthy Living Areas (Barton ve Grant, 2006)

The healthy city approach consists of basic elements such as accessible and safe public spaces, environmental sustainability, community participation and social justice. These elements increase the quality of life of individuals and promote equality and justice in urban areas. Green areas and pedestrian-friendly cities create a sustainable environment that supports environmental health and increases resilience to climate change. Therefore, this holistic approach is of great importance in the construction of healthy living environments.

3. Urban Design Competitions and Healthy City Concept

Architectural competitions are important tools that enable the emergence of innovative ideas in spatial design. Since the projects presented in competitions are mostly evaluated in terms of aesthetic and visual quality, user needs and spatial performance may remain in the background. As a matter of fact, the dominance of subjectivity in the specification structures and jury evaluation processes of competitions is one of the main factors that negatively affects the functionality of the design (Akçay, 2021). "Urban design competitions should be evaluated not only based on aesthetic qualities, but also according to criteria such as sustainability, accessibility, and healthy living conditions." (Arkun, 2021).

Architectural design competitions are important tools that encourage the development of innovative and qualified solutions in the field of urban design. They bring together different perspectives, enable the emergence of creative ideas and pave the way for designs that are in the public interest. Especially in projects for public spaces, competitions provide a transparent and participatory process, contributing to the selection of applications that increase the quality of the urban environment. It is an effective method for local governments to achieve sustainable, accessible and socially sensitive designs.

Within the scope of this study, the definition and objectives of two international project competitions closely related to the urban design discipline are explained. Then, the projects that have won awards in the last five years have been examined with visuals in line with the official websites of the competitions and project description reports. The aspects of each project that can be associated with the healthy city approach have been determined and evaluated under these headings. Thus, how healthy city principles are reflected in contemporary urban design practices has been revealed through concrete examples.

Peter G. Rowe (2021) emphasizes that the Veronica Rudge Green Urban Design Award plays an important role in evaluating innovative approaches in the urban design discipline and highlighting successful projects. According to Rowe, this award provides an important opportunity to understand the design problems faced by cities on a global scale, to compare the effectiveness of different approaches and to determine successful strategies. This award, given by Harvard University since 1986, rewards projects that reflect the core values of urban design, focusing on large-scale urban transformation projects, infrastructure development works and public space designs. Thus, the award encourages urban design practices that support not only the physical structure of cities but also social and environmental sustainability (Rowe, 2021, https://urbandesignprize.gsd.harvard.edu/). The Veronica Rudge Green Urban Design Award rewards exemplary urban design projects that reveal a humane and valuable aspect in the design of urban environments.

The European Prize for Urban Public Space Award is an international awards program that has been organized every two years since 2000 and encourages the creation, reuse and improvement of public spaces in European cities. The main aim of the competition is to emphasize the importance of public space as a democratic value and to make visible the contribution of disciplines such as architecture, landscape and urbanism to urban life. Taking as its evaluation criteria qualities such as social inclusiveness, environmental sensitivity and cultural continuity as well as physical quality, this award aims to support the common culture of public space production of European cities.

3.1. Review of Selected Competition Projects

3.1.1.Veronica Rudge Green Prize for Urban Design -2023 Award- Grand Paris Express

The 14th Veronica Rudge Green Urban Design Award was awarded to the Grand Paris Express, a large-scale public transport project currently under construction in and around the Paris metropolitan area. The Grand Paris Express aims to change the mono-centric urban model of Paris and make public transport more inclusive. The project promotes more efficient transport by reducing the use of private cars and reducing the carbon footprint. It aims to increase the sustainability of Paris by establishing fast and environmentally friendly connections between the existing city peripheries and developing areas. These connections support the creation of new urban centres. A transport network has been created that connects the outer regions without directly passing through the city centre. The architectural projects connected to the Grand Paris Express are developed independently and are carried out by architects, designers and artists. Each project is shaped by local needs and adheres to community participation processes. It follows the general principles set for public spaces and future projects.

Fig.2. The Grand Paris Express project (URL-1, URL-2)

Design approaches that stand out in relation to Healthy City:

- Sustainable Transportation and Reduced Carbon Footprint
- Inclusive and Accessible Public Transportation
- Environmental Sustainability
- Art and Cultural Integration
- Innovative and Sustainable Design Approaches

3.1.2. Veronica Rudge Green Prize for Urban Design-2017 Award- High Line (New York)

The High Line project is an innovative public space project that combines urban transformation and landscape architecture. Created by transforming a disused industrial railway line in New York, this urban park adopts sustainable design principles. The landscape is shaped with dynamic routes that encourage pedestrian circulation, and the use of public space is increased. It creates a green corridor within the dense building texture of the city by combining architectural, ecological and social components. Independent pedestrian flow from ground level increases mobility within the city, while providing a natural environment rich in flora and fauna. The project supports social interaction with contemporary spatial interventions while preserving urban heritage. The High Line is considered an exemplary model in terms of sustainable urban design and re-functioning of public spaces.

Fig.3. High Line Project (URL-3)

Design approaches that stand out in relation to Healthy City:

- Green Space and Biodiversity
- Pedestrian Friendly Urban Design
- Re-Functioning of Public Spaces
- Encouraging Physical Activity
- Environmental Sustainability
- Social Integration and Community Participation
- Improving Air Quality and Urban Microclimate

3.1.3.Veronica Rudge Green Prize for Urban Design -2015 Award- Madrid Rio (Madrid, Spain)

The Madrid Río project is a comprehensive public space intervention that aims to transform urban infrastructure and integrate it into urban life. The area gained by moving the M-30 highway underground has been transformed into a linear landscape park on the riverside. The project provides spatial continuity with green infrastructure, ecological corridors, recreational areas and social facilities. This design, which integrates historical structures with contemporary elements, establishes a balance between cultural heritage and current needs. It encourages collective life with a pedestrian-first circulation system, bicycle paths and public meeting areas. Madrid Río is one of the examples of healthy urban environment production with its sustainability, accessibility and multifunctionality principles.

Fig.4. Madrid Río Project (URL-4)

Design approaches that stand out in relation to the Healthy City:

- Putting the highway underground, green space and clean air
- Creating a linear landscape axis
- Strengthening pedestrian and bicycle infrastructure
- Recreational and cultural open spaces
- Preservation and integration of historical structures

- Water management and environmental resilience
- Inclusive and interactive public spaces

3.1.4. Veronica Rudge Green Prize for Urban Design -2013 Peer Award -Metro do Porto (Porto, Portugal)
There are two projects that have been awarded the Veronica Rudge Green Urban Design Award in 2013:

1. Metro do Porto (Porto, Portugal): Designed by architect Eduardo Souto de Moura, this project aims to increase urban mobility by improving the public transportation infrastructure of the city of Porto.
2. Northeastern Urban Integration Project (Medellín, Colombia): Sponsored by the Municipality of Medellin, this project aims to strengthen social and spatial integration in the northeast of the city.

The Metro do Porto project has advanced with a respectful approach to the historical heritage while transforming the urban fabric on a large scale. The design, developed under the leadership of Eduardo Souto de Moura, has transformed the transportation infrastructure into spatial elements that are not only functional but also support public life. The stations are considered as open spaces integrated with the city; topography and architecture are integrated harmoniously with the environmental context. This approach reflects a sustainable and holistic design vision that enhances the quality of the public space beyond transportation.

Fig.5. Metro do Porto Project (URL-5)

Design approaches that stand out in relation to the Healthy City:

- Development of accessible public transport infrastructure
- Production of public spaces sensitive to historical texture
- Pedestrianization of public spaces and environmental improvement
- Promotion of sustainable urban transport
- Support for social integration

3.1.5. Veronica Rudge Green Prize for Urban Design 2013 Peer Award- Northeastern Urban Integration Project (Medellin, Colombia)
This project, implemented in the marginalized northeastern neighborhoods of Medellin, is a social transformation program that aims to reduce spatial inequalities. While access is provided in the steep topography with the MetroCable system, an inclusive urban network has been built with new public spaces, education and cultural structures. The design process was shaped by a participatory approach; a strategy focused on social belonging, security and quality of life was adopted beyond physical interventions. The project is a holistic intervention that reveals the capacity of architecture to produce social impact.

Fig.6. Northeastern Urban Integration Project (URL-5)

Design approaches that stand out in relation to Healthy City:

- Equal access despite topographic barriers
- Increasing the quality of public life in low-income neighborhoods

- Inclusive urban infrastructure strategy
- Community participation-based decision-making process
- Safe and socially functional open space production

3.1.6. Veronica Rudge Green Prize for Urban Design –2010 Award-Cheonggyecheon Restoration Project (Seoul, South Korea)
The Cheonggyecheon Stream Restoration Project stands out by transforming a defunct highway in the center of Seoul into an ecological corridor that revitalizes public life. The project demonstrates the transformative power of urban design by combining environmental sustainability, social integration, and economic revitalization. The system, integrated with topography and infrastructure, was implemented with public participation, political will, and interdisciplinary collaboration; while improving the natural ecosystem, it strengthens public transportation and pedestrian connections. As a symbol of qualitative transformation in Asian urban design, Cheonggyecheon offers a contemporary model that aligns with healthy city principles.

Fig.7. Cheonggyecheon Restoration Project (URL-6)

Design approaches that stand out in relation to Healthy City:
- Restoration of green space and natural water ecosystem
- Microclimate arrangements that reduce urban heat island effect
- Pedestrian priority circulation network and public space continuity
- Improvement of air quality and environmental health through ecological restoration
- Social spaces and cultural areas that encourage public life
- Integrated consideration of social, economic and environmental sustainability in the city center

The European Prize for Urban Public Space is an international evaluation platform held every two years, aiming to recognise and make visible work on the design, improvement and re-functioning of public spaces in European cities.

3.1.7.The European Prize for Urban Public Space-2024 Award- Park at the Warsaw Uprising Mound Warsaw (Poland)

The new park in the centre of Warsaw was built by reusing the remains of World War II. This approach combines historical memory with contemporary landscape design. The park offers a multi-layered spatial structure that combines commemoration, ecological sensitivity and public life. It provides an inclusive public experience through walking routes compatible with the topography and accessible circulation systems. With silent commemorative areas, green infrastructures and flexible spatial arrangements that allow for outdoor activities, the project demonstrates a design approach that is in line with healthy city principles.

Fig.8. Park at the Warsaw Uprising Mound Project (URL-7)

Design approaches that stand out in relation to the Healthy City:

- Inclusive design that makes historical memory visible in public spaces
- Environmental sustainability through the transformation of war remains
- Accessible, disabled-friendly pedestrian paths and circulation systems
- Nature-based landscape design compatible with topography
- Recreational public spaces suitable for outdoor activities
- Green infrastructure applications that increase ecological sensitivity
- Multifunctional spaces that support silent commemoration, social interaction and physical activity
- Public use that keeps urban memory alive and supports cultural continuity

3.1.8. The European Prize for Urban Public Space -2022 Prize-Catharijnesingel- Utrecht (Netherlands)
Catharijnesingel is a design intervention focused on ecological restoration and re-functioning of public space, implemented by reclaiming a historical water channel in the city center of Utrecht, the Netherlands. The old channel, which was converted into a motorway in the 1970s, was rebuilt with a contemporary landscape approach based on the integration of water and green space. While reviving the urban memory, the project also fulfills environmental functions such as rainwater management and heat island reduction in the context of the climate crisis. Pedestrian and bicycle-oriented circulation systems encourage sustainable transportation by pushing the priority use of cars into the background. Catharijnesingel is a qualified example of urban transformation that contributes to healthy city goals with nature-based solutions, historical continuity and public accessibility principles.

Fig.9. Catharijnesingel Project (URL-8)

Design approaches that stand out in relation to the Healthy City:

- Ensuring ecological integrity by restoring the historical water channel
- Rainwater management and microclimate regulation
- Sustainable transportation system focused on pedestrians and bicycles
- Improving air quality by reducing motor vehicle traffic
- Increasing accessibility of public spaces
- Increasing urban resilience with nature-based solutions
- Strengthening cultural continuity and place identity related to urban memory

3.1.9. The European Prize for Urban Public Space -2018 Award-Renovation of Skanderbeg Square Tirana (Albania)
Skanderbeg Square represents the transformation of Tirana's center from a car-focused area to a people-focused and public space. The project aimed to create a multifunctional open public space that would breathe life into the city by pedestrianizing the 40,000 m² central area. It was designed with a spatial structure that regulates the urban microclimate and directs public circulation with its slightly elevated form and surrounding green belt. The use of local stone materials emphasized geographical identity and cultural diversity; the square was transformed into a center that allows flexible use for ceremonies, rest, socializing and daily life. This approach is integrated with healthy city principles such as the strengthening of public life, accessibility and environmental awareness.

Fig.10. Renovation of Skanderbeg Square Project (URL-9)

Design approaches that stand out in relation to the Healthy City:

- Pedestrianized city center by removing vehicle traffic
- Accessible and disabled-friendly public space design
- Opportunity for physical activity and socialization with wide open spaces
- Cultural continuity and place identity emphasis with the use of local stone
- Multifunctional and flexible use areas that support public life
- Surface design integrated with topography and gently sloping square design
- A symbolic, inclusive and democratic public space production

3.1.10. The European Prize for Urban Public Space -2016 Award- Recovery of the Irrigation System at the Thermal Orchards Caldes de Montbui (Spain)

This project aimed to re-establish both ecological functionality and cultural continuity through the restoration of the traditional irrigation system in Termal Bahçeler, a historical agricultural area. This rural landscape, which functions as a social production area, was re-functioned with nature-based solutions and low-intervention strategies; and opened to public use through a process developed on the basis of community participation. The project is an example of spatial integrity across scales, bringing together healthy urban components such as food production, water management, heritage protection and social interaction.

Fig.11. Recovery of the Irrigation System at the Thermal Orchards Caldes de Montbui Project (URL-10)

Design approaches that stand out in relation to Healthy City:

- Preservation of traditional irrigation infrastructure and restoration of its ecological function
- Promotion of food security through community-supported agriculture
- Sustainable approach to water management and natural resource use
- Creation of production-based social interaction environments in public open spaces
- Protection of rural landscapes
- Development of environmental awareness through nature-based solution proposals

3.1.11.The European Prize for Urban Public Space-2014 Co-Prize- The Braided Valley, Elche (Spain)

The Braided Valley is the re-use of a long-abandoned area along the Besòs River in the north of Barcelona, through a process of ecological rehabilitation and public transformation. The project integrates green infrastructure, walking and cycling routes, natural floodplains and ecological landscape elements, with the aim of revitalizing the aquatic ecosystem and creating a network of open spaces integrated with the surrounding settlements. Its name, meaning “braided valley”, represents a permeable public space structure where the natural topography and the cultural landscape are intertwined. The project is an example of a holistic urban ecology based on the principles of water management, environmental sustainability and accessibility, in line with the healthy city approach.

Fig.12. The Braided Valley Project (URL-11)

Design approaches that stand out in relation to Healthy City:

- Creating accessible linear green corridors closed to vehicle traffic
- Strengthening pedestrian and bicycle connections connecting the two sides
- Revitalizing the river ecosystem and protecting the natural landscape
- Nature-based solutions that support climatic and ecological diversity
- Open spaces that support social integration and healthy lifestyles

3.1.12.The European Prize for Urban Public Space -2014 Co-Prize-Redevelopment of the Old Port Marseille (France)

Redevelopment of the Old Port is a comprehensive transformation project that aims to reintegrate the historic port area of Marseille into urban life by freeing it from the pressure of motor vehicles. The project has created a public space with pedestrian priority by limiting vehicle traffic around the port and has provided uninterrupted circulation along the port's coastline. The use of natural stone and spatial simplicity in surface arrangements have given it a character that is in harmony with the historical context. In addition, open spaces suitable for multifunctional use revitalize public life for both daily socializing and cultural events. The project supports a healthy city approach with the principles of social inclusion, accessibility and sustainable design compatible with the coastal ecosystem.

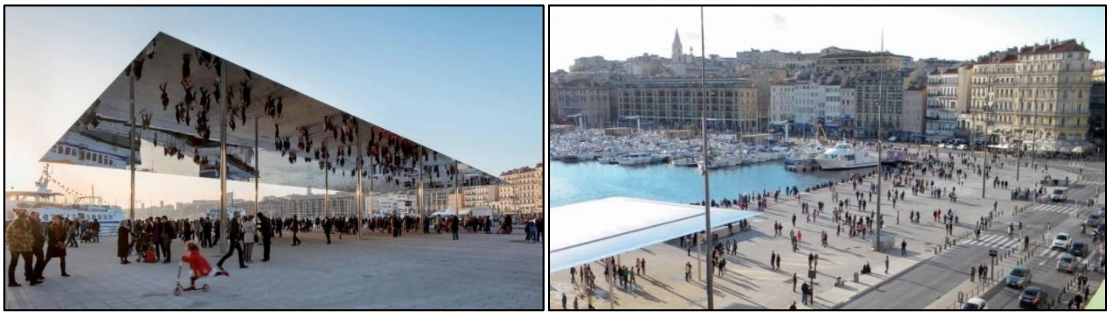

Fig.13. Redevelopment of the Old Port Marseille Project (URL-11)

Design approaches that stand out in relation to the Healthy City:

- Reducing vehicle traffic and creating pedestrian-first public space
- Establishing a circulation system that provides uninterrupted access along the coast
- Multi-functionality in public space: socializing, resting, cultural activities
- Harmonizing the environmental and historical context with natural stone floor coverings
- Accessible design for everyone, including the disabled
- Open space strategies that strengthen the city-coast relationship
- Improving microclimate comfort with shade and open surfaces

4. Finding

Within the scope of this study, the evaluations regarding the projects under consideration were carried out based on the project identities, explanatory texts and documents containing the project scopes on the official websites of the relevant competitions. The explanatory reports detailing the architectural approach, implementation process and objectives for each project were examined; in line with these documents, nine basic principles that can be associated with the healthy city approach were determined. These principles represent the intervention areas that contribute to urban health or aim to improve this area in the projects in question.

Then, analytical tables containing the titles "Healthy City Principle", "Justification / Need" and "Intervention / Application Method" were created within the framework of these principles for each project. The basic assumption here is that the projects aim to intervene in these deficiencies by identifying some healthy living conditions that are seen as deficient or problematic in cities. The evaluation method developed within this framework offers a reading style that establishes a cause-effect relationship in the competition projects and aims to reveal how the design interventions overlap with the healthy city components.

The projects analyzed in this study were evaluated based on the implementation levels of the healthy city approach in line with the principles set forth by the World Health Organization and contemporary literature. These principles were grouped under the following headings: green space / ecological corridor, pedestrian-friendly transportation, accessibility, air quality / ecological restoration, water management, environmental sustainability, social equality and inclusiveness, community participation, and integration of cultural and historical heritage. Each project was examined separately within the scope of these principles; it was not expected that all principles would be present in each project.

Healthy City Principles Based on Tables (headings)

- Green Area / Ecological Corridor
- Pedestrian Friendly Transportation
- Accessibility
- Air Quality / Ecological Restoration
- Water Management
- Environmental Sustainability
- Social Equality and Inclusion
- Community Participation
- Integration of Cultural and Historical Heritage

Table 1. Healthy City Principles in Urban Design Competitions: Project-Based Comparative Table of Interventions and Rationales

Competition	Winning Project Information	Healthy City Principle	Reason / Need	Intervention / Application Method
Veronica Rudge Green Prize	2023– Grand Paris Express- Paris / France	Accessibility	Lack of integration of urban peripheries with the center, unequal transportation network	New metro lines integrated peripheral areas into the center; direct connection to the ring system was established
		Community Involvement	Necessity of user-centered solutions in complex spatial networks	Architectural projects were developed independently according to regional needs, participatory processes were adopted
		Environmental Sustainability	Reducing vehicle dependency, targeting reduction of carbon emissions	Public transport infrastructure was strengthened; private car use was designed to be reduced
		Social Equality and Inclusion	Unequal use of urban opportunities by those living in urban peripheries	New lines provided spatial integrity that reduced social exclusion
Veronica Rudge Green Prize	2017– High Line- New York / ABD	Green Space / Ecological Corridor	Lack of contact with nature in urban density, inadequate public green spaces	Abandoned railway line transformed into a linear public park, natural vegetation redesigned
		Pedestrian Friendly Transportation	Lack of safe and uninterrupted pedestrian routes due to traffic density	Planned as a raised, traffic-free pedestrian path; entire route made accessible
		Environmental Sustainability	Need to reduce water waste, reduce urban heat island effect	Environmentally friendly landscape design implemented with drip irrigation system, drought-resistant plants and water-retaining surfaces
		Community Participation	Need for local communities and users' opinions in the design process	Public feedback was received during the planning process, volunteer-supported maintenance processes were developed
		Social Equity and Inclusion	Need for different age and social groups to meet in common areas	Socialization was encouraged with public event spaces, seating and rest areas
Veronica Rudge Green Prize	2015 – Madrid Río- Madrid / Spain	Green Space / Ecological Corridor	The need to reintegrate the green tissue interrupted by the busy highway	The highway was taken underground; a linear ecological corridor was created with 120 hectares of green space, parks and vegetation

Table 1.Continued

		Pedestrian Friendly Transportation	Access problems and inadequate urban circulation due to vehicle-oriented planning	30 km of bicycle and pedestrian paths were built; 11 new pedestrian bridges facilitated circulation on both banks of the river
		Water Management	Uncontrolled use of riverbeds and flood risk	The Manzanares River area was arranged with ecological landscaping; the water regime was balanced
		Social Equality and Inclusion	Inequality in the sharing of urban spaces among social groups	Various uses such as sports, culture, recreation and children's games were provided in public areas
		Integration of Cultural and Historical Heritage	Historical structures had a weak relationship with the current environment	Historical bridges and infrastructures were restored and integrated with new green spaces
Veronica Rudge Green Prize	2013 – Metro do Porto	Environmental Sustainability	The need to increase the quality of urban life and strengthen the relationship with nature	Sustainable transportation, natural landscape elements and recycling systems were integrated
		Accessibility	Structural inequality in transportation from the city periphery to the center	Inclusive transportation provided with the metro network
		Pedestrian Friendly Transportation	Lack of pedestrian movement around stations	Pedestrian-oriented areas were created with environmental design
		Integration of Cultural and Historical Heritage	Necessity of compliance with UNESCO area	Sensitive transitions were provided in the architectural language
		Environmental Sustainability	Carbon impact of vehicle dependency	Carbon footprint was reduced with public transportation
	2013 – Northeastern Urban Integration Project	Accessibility	Physical obstacles in transportation of steeply sloped areas to the center	Neighborhoods were connected to the city center with the MetroCable system
		Social Equity and Inclusion	Social exclusion due to poverty and lack of services	Quality of life was increased with public facilities and social spaces
		Community Participation	Exclusion of local people in the urban transformation process	Public participation was ensured in decision-making processes
		Environmental Sustainability	Intensive construction and loss of natural areas	New public spaces and green areas were integrated
Veronica Rudge Green Prize	2010 – Cheonggyecheon- Seul / South Korea	Green Space / Ecological Corridor	Lack of green space in the city center and the river being hidden in a concrete channel	The highway was removed and a linear ecological green corridor was created
		Air Quality / Ecological Restoration	Increased air pollution and heat island effect due to vehicle traffic	The highway was removed, the microclimate was improved with green areas and water elements
		Water Management	Flood risk and uncontrolled water regime	The natural flow of the river was restored, water management infrastructure was integrated
		Community Participation	Public support in urban-scale transformation and the need to determine user needs	Public information and broad participation consultations were carried out during the design process
		Social Equity and Inclusion	Different user profiles not being able to meet in a common area	Public spaces were made accessible to various age and social groups
The European Prize for Urban Public Space	2024 – Storm Action Park-Warsaw / Poland	Integration of Cultural and Historical Heritage	The forgotten historical memory of the World War II ruins area	Topography preserved, historical memory spatially represented without monumental elements
		Green Area / Ecological Corridor	Lack of contact with nature in urban density	Unbuilt areas reorganized as green areas
		Social Equality and Inclusion	The need for children, the elderly and different social groups to access a common space	Inclusive public space design including play and recreation areas
		Environmental Sustainability	Promotion of permeable surfaces compatible with the natural water cycle	Low-impact solution implemented by considering water management and green infrastructure together

Table 1.Continued

The European Prize for Urban Public Space	2022- Catharijnesingel – Utrecht	Water Management	Loss of ecological functions of canal filled in 1970s	The canal was reopened to restore natural water flow and biodiversity
		Green Space / Ecological Corridor	Break of ecological connections in urban areas	The urban ecology was revitalized with linear green areas and natural habitats
		Pedestrian Friendly Transportation	Car-focused planning limits pedestrian mobility in city centers	Vehicle paths were removed and the canal shore was transformed into walking paths
		Environmental Sustainability	Need for urban nature-based solutions to combat climate change	Water, green infrastructure and biophilic design were implemented in a holistic manner
The European Prize for Urban Public Space	2018- Renovation of Skanderbeg Square Tirana (Albania)	Pedestrian Friendly Transportation	The density of vehicle traffic and inadequacy of pedestrian areas in the city center	The square was completely pedestrianized, vehicle traffic was eliminated and wide pedestrian areas were created
		Integration of Cultural and Historical Heritage	Emphasizing the historical importance of the square and reflecting the national identity	Mosaic patterns were created on the floor with stones brought from different parts of the country
		Green Area / Ecological Corridor	Lack of green space in the city center and the need to increase biodiversity	12 green gardens were added around the square to support urban ecology and improve microclimate
		Social Equality and Inclusion	Limitations in access of different social groups to common public spaces	The square was designed as an inclusive and accessible public space open to all citizens
The European Prize for Urban Public Space	2016 – Thermal Orchards- Caldes de Montbui / Spain	Water Management	Pollution of irrigation system with sewage and lack of clean water	Sewage was rerouted to provide clean water to old irrigation areas
		Green Space / Ecological Corridor	Loss of environmental and ecological function of abandoned agricultural lands	Gardens were repurposed and transformed into productive green spaces connected to the city
		Community Participation	Dispersion of gardening community and weakening of social interaction	A collective design and implementation process was carried out with the participation of more than seventy gardeners
		Accessibility	Difficult access to gardens, disconnection from urban center	A new network of pedestrian paths was created connecting the gardens to the town center
The European Prize for Urban Public Space	2014 – The Braided Valley-Elche / Spain	Pedestrian Friendly Transportation	The riverbed is a barrier dividing the city into two and pedestrian access is limited	The two sides of the city were connected with a network of pedestrian paths and bridges
		Green Space / Ecological Corridor	The riverbed is inactive and has low ecological value	An ecological corridor was created by landscaping with local plant species
		Community Participation	The risk of ignoring user needs in the project design	A temporary office was established and the most preferred routes by users were determined and integrated into the design
		Accessibility	The riverbed is disconnected from the surrounding neighborhoods	Connections between neighborhoods were strengthened with pedestrian paths and bridges
The European Prize for Urban Public Space	2014- Redevelopment of the Old Port – Marseille	Pedestrian Friendly Transportation	Restriction of pedestrian mobility due to heavy vehicle traffic around the port	The port area was cleared of vehicles, pedestrian paths were widened and public spaces were created
		Accessibility	Lack of barrier-free and equal access to public spaces	The port and its surroundings were arranged to be accessible to everyone, including disabled individuals
		Environmental Sustainability	Increased heat island effect due to dense hard surfaces	Permeable, environmentally sensitive surfaces were created using natural granite stone
		Social Equity and Inclusion	Ownership of the port by only certain user groups	With inclusive spatial arrangements, the port was made an area that everyone can use

The tables presented above reveal that award-winning urban design projects implemented in different geographies and scales provide multidimensional contributions to the healthy city approach. A large portion of the projects include strategic interventions aimed at improving the quality of urban life in areas such as social equality, participation, protection of cultural heritage and environmental sustainability, as well as improving the physical environment. In these projects, topics such as pedestrian-first transportation, increasing green areas and increasing contact with nature are widely prominent; processes that encourage community participation are supported by solutions that are sensitive to local needs. The findings obtained from the table show that healthy city principles are not only a theme in current urban design practices, but also a holistic approach. Table 2 presents the extent to which the healthy urban design principles defined within the scope of this study are addressed in award-winning urban design projects. Due to visual constraints, the column headers in the table are numbered as follows: (Item-1) Green Space / Ecological Corridor, (Item-2) Pedestrian-Friendly Mobility, (Item-3) Accessibility, (Item-4) Air Quality / Ecological Restoration, (Item-5) Water Management, (Item-6) Environmental Sustainability, (Item-7) Social Equity and Inclusiveness, (Item-8) Community Participation, and (Item-9) Integration of Cultural and Historical Heritage. Similarly, the analyzed projects are coded as Project-1, Project-2, etc., in accordance with the order mentioned above. In this way, the degree to which each project aligns with the healthy city principles can be analyzed in a systematic and comparative manner.

Table 2. Urban Health Principles in Design Competitions: A Thematic Summary

Project Name	**Award Year**	**Item-1**	**Item-2**	**Item-3**	**Item-4**	**Item-5**	**Item-6**	**Item-7**	**Item-8**	**Item-9**
Project-1	2023			✓			✓	✓	✓	
Project-2	2017	✓	✓				✓	✓	✓	
Project-3	2015	✓	✓			✓	✓	✓		✓
Project-4	2013		✓	✓			✓			✓
Project-5	2013			✓			✓	✓	✓	
Project-6	2010	✓			✓	✓		✓	✓	
Project-7	2024	✓					✓	✓		✓
Project-8	2022	✓	✓			✓	✓			
Project-9	2018	✓	✓					✓		✓
Project-10	2016	✓		✓		✓			✓	
Project-11	2014	✓	✓	✓					✓	
Project-12	2014		✓	✓			✓	✓		

As a result, the table showing the distribution of projects according to principles visually demonstrates how the healthy city approach finds a response in different scales and contexts within the scope of competition projects. It is observed that the vast majority of the twelve projects examined focus particularly on the principles of green areas/ecological corridors, environmental sustainability and pedestrian-friendly transportation. This situation indicates that the reorganization of the physical environment and the creation of spaces integrated with nature are prioritized in terms of urban health. On the other hand, the fact that socially focused principles such as community participation, integration of cultural heritage and social equality are represented in a more limited number of projects shows that these headings are not addressed as strongly as spatial intervention. Nevertheless, the majority of the projects simultaneously meet at least three or more healthy city principles; this reveals that multi-dimensional, integrated approaches are adopted in the design process. As can be visually observed in the table, the concept of healthy city is not limited to the physical environment in competition projects, but is addressed together with social and ecological integrity goals.

5. Evaluations and Conclusion

When the competition projects are evaluated based on their description reports and project identities, it is observed that a significant portion of the projects that have won awards in recent years overlap with the healthy city approach at various levels. The findings reflected in the table show that there is an awareness of the principles of green space production, pedestrian-friendly transportation and accessibility in most of the projects. These topics stand out as recurring themes in the context of both large-scale infrastructure transformations and small-scale spatial interventions.

In contrast, principles such as social equality and inclusiveness, air quality and ecological restoration are emphasized in fewer projects. This may suggest that in some projects the social dimension is not directly reflected in spatial design or is not sufficiently visible in the disclosure reports. Similarly, the integration of cultural and historical heritage is also highlighted in a limited number of projects as a principle that only comes to the fore in the context of certain cities.

In particular, projects such as Cheonggyecheon, Madrid Rio and the High Line respond to a large number of healthy city principles, while some projects are more limited but deepen in certain themes. This distribution reveals that the projects that won awards in the competitions were shaped at different scales and contextual conditions, and therefore their contributions to the healthy city approach were also affected by these differences.

Although this study is not based on the assumption that the competition projects are directly produced in line with healthy city principles, as a result of the examinations, it has been observed that many projects develop spatial approaches that are consistent with these principles. In line with the themes highlighted in the explanatory reports; it is understood that the projects generally carry partnerships aimed at transforming cities in a more livable, accessible and public health-supporting manner. In this context, beyond producing only aesthetic or technical solutions, competition projects offer significant potential in reflecting the healthy city vision on space and in this respect create a remarkable intellectual environment for future urban design policies.

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The impact of socio-cultural change in rural areas on the built environment: The case of Ataköy, Trabzon

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Abstract: The rural area, until recently defined by its independent, unique and autonomous characteristics, is now in an intense and inevitable interaction with urban areas and communication networks. While this interaction is changing the economic, cultural and social structure of the rural area, it is also bringing about its spatial transformation.. This interaction, while causing changes in the economic, cultural, and social structure of the rural, also brings about its spatial transformation.The study focuses on the impact of the socio-cultural change caused by the population movement that began in the 1950s and continues in various forms today on the rural built environment and aims to open a discussion on the possibility of preserving the traditional built environment in a rural settlement where the traditional way of life has lost its influence by addressing the residential buildings in Ataköy neighbourhood of Çaykara district, Trabzon province, in chronological order. In this context, the aim is to examine the socio-cultural change in the settlement and its impact on the space by determining the current adaptation strategies and house preferences in Ataköy. The study makes use of archival work, field observation and structural environmental analysis.

Keywords: Socio-cultural change; Rural area; Migration; Traditional built environment; Ataköy

1. Introduction

1.1. Rural-Urban Interaction

The interaction that began with the Industrial Revolution and continued under the influence of globalization, the spatial boundaries between rural and urban areas have been disappearing, and rural areas have been increasingly becoming extension of the urban(Ceylan & Somuncu, 2018). Rural areas are transforming into urban areas, used by urban populations and controlled and managed by urban institutions (Ceylan & Somuncu, 2020). With the urbanization of rural areas, it is argued that entire of the world will eventually become urban space and that it is no longer possible to stop urbanization (Ceylan & Somuncu, 2018; Tekeli, 2011: 496-497).

The rural area, by nature, has a permeable structure (Kaya, 2011) and this permeable structure of the rural area and its spontaneous formation make it easily influenced by the dynamics it is exposed to. Until recently, the rural area has been defined by its independent, unique, and autonomous characteristics. However, today, it is engaged in intense and inevitable interaction with urban and its communication networks. This interaction, while causing changes in the economic, cultural, and social structure of the rural, also brings about its spatial transformation.

Socially, the rural area has a community structure based on personal trust, moral norms, and traditions, developing an autonomous system through kinship/neighborhood relationships. In this context, it is far from the social order developed within the framework of institutionalized mechanisms and legal regulations in the city (Altun et al., 2020:43). However, as the rural area enter the urban production and consumption networks and become part of urban production economically, its self-sufficient autonomous structure is damaged. While the pursuit of a better life and employment opportunities draws rural families to the cities, adaptation to urban forms of relationships becomes an obligation. With the influence of urbanization and globalization, members of the community who become part of a shared cultural system become more inclined to seek return their local identities and make a place their own in rural area with a sense of belonging. For members of the community who have migrated to urban, the rural continues to hold symbolic significance as "ancestral land" or the "father's house." It becomes a place to which they return during holidays. For some, it is the residence of extended family members; for others, it represents the setting of their childhood; and for many, it is where the graves of deceased relatives are located (Altun et al., 2020: 53). In this context, the rural area becomes the source of collective memory, keeps

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the community together and playing a crucial role in sustaining the cultural continuity (Altun et al., 2020: 53). On the other hand, it also provides an opportunity for individuals who, through migration from rural to urban, have achieved economic, cultural, and social gains and ascended to a higher social status, to showcase their gains. These dynamics create disintegration in the social and cultural structure of the rural area, while also affecting its spatial structure. While traditions, the norms that bring the community together, and the spiritual feelings related to space are relatively fading, the symbolic role of traditional values is taking precedence over their functional role (Altun et al.,2020:44) The individualization and consumer culture associated with globalization, along with the change in social class, leads to the desire for a more comfortable life and the tendency to display the new identity and status gained by individuals. This situation creates problems in the adaptation of individuals returning to the countryside to the rural built environment designed according to traditional production and lifestyles, and leads to the emergence of different coping strategies in achieving adaptation. Gür (1996) mentions three strategies for individuals to achieve harmony with their environment: changing the macro-environment (relocation, migration, etc.), changing the meso or micro-environment, i.e. changing housing or behaviour, or changing values and perceptions, and states that this is the only way to prevent cognitive dissonance. Rapoport (2005) and Berry (1980), on the other hand, state that adaptation is achieved through four types of methods: changing actions and behaviours (reaction), altering or redesigning the environment (adjustment), relocation (withdrawal), and surrender (giving up).

1.2. Rural-Urban Interaction and Migrations in Turkey

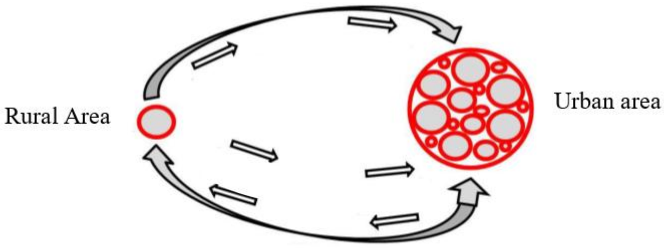

Fig. 1. Population movement between rural and urban areas in Turkey (Özden&Özden,2019)

Although the interaction between rural and urban areas in Turkey was weak until the early years of the republic, economic development efforts that began in the 1950s and improvements in transportation and communication facilities such as highways and radio made cities attractive to rural people and triggered rural-urban migration. In the 1970s, rural areas were seen as places that needed to be improved or reformed as an expression of backwardness; while migration from rural area to urban increased, various projects were developed by the state for the development and modernization of rural areas (Tunçdilek, 1978; Ceylan & Somuncu, 2020; Özden & Özden, 2019). In the 2000s, while improvements in technology, mass media and infrastructure systems allowed individuals to move more easily, population growth in cities and problems arising from globalization caused reverse migration from urban to rural areas (Fig. 1).Güreşçi (2010) states that this population movement causes individuals to prefer their place of residence and consequently to change their place in the social stratum and that migration is one of the most important reasons for economic, social and cultural change in Turkey. Migration is defined as a movement of population, which basically refers to the physical attachment of people to certain places, starting in one place and ending in another, arising from the search for a better life (Südaş & Mutluer, 2010). However, with globalization and the transition to the information society, relocation is no longer a rare and obligatory event, but has become a part of life. For this reason, it is stated that the concept of migration is insufficient to understand today's population movements (Tekeli,2007:471). Developing communication and transportation facilities liberate individuals from being tied to certain centers and offer opportunities that respond to the desire to live using more space. Today, this allows for a different kind of population movement, characterized by people who are not tied to one place, who have the ability to move, and who have a relatively high level of well-being. In the background of this mobility, there is the idea of living in a settled spatial and social environment, engaging in gardening, etc., spending time with family elders and children, taking longer vacations with less expenditure, and gaining status in society by owning a second home. Migration may have been permanent or seasonal, with time spent in the destination ranging from half the year, almost the entire year, or the whole year. The duration could vary depending on factors such as family, relatives, and children connections, ongoing work, or health issues (Südaş & Mutluer, 2010).

1.3. Aim and Scope

The study focuses on the impact of the socio-cultural change caused by the population movement that began in the 1950s and continues in various forms today on the rural built environment and aims to open a discussion on the possibility of preserving the traditional built environment in a rural settlement where the traditional way of life has lost its influence by addressing the residential buildings in Ataköy neighbourhood of Çaykara district, Trabzon province, in chronological order. In this context, the aim is to examine the socio-cultural change in the settlement and its impact on the space by determining the current adaptation strategies and house preferences in Ataköy. The study makes use of archival work, field observation and structural environmental analysis.

2. Material and Method

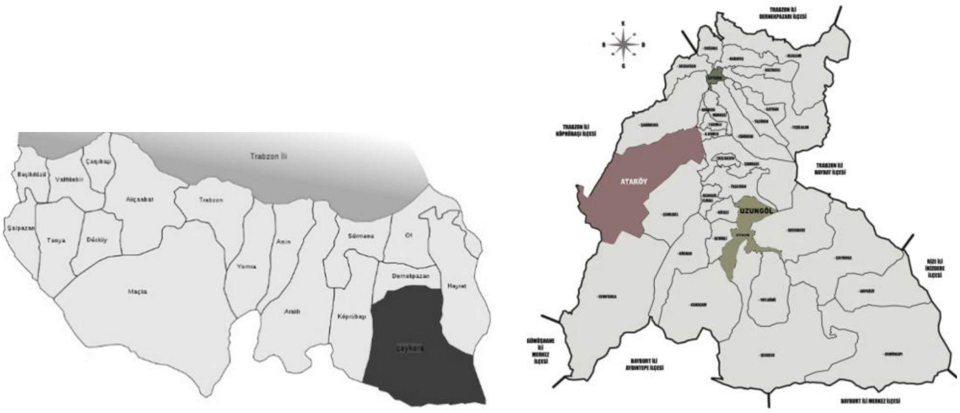

Fig. 2. On the left, the location of Çaykara in Trabzon, on the right, the location of Ataköy in the district

Table 1. Population of Ataköy over the years (URL1,2025)

Year	1960	1970	1980	1990	2000	2010	2024
Population	2037	2747	1478	1220	711	1691	631

Ataköy is located in the southwest of the Çaykara District in Trabzon Province, approximately 9 kilometers from Çaykara (Fig.2). The settlement, which gained the status of a town municipality in 1957, was transformed into a neighborhood under the Metropolitan Municipality Law in 2014. Since the 1960s, development of building environment was visioned according to zoning plans however, these plans have not evolved into an effective implementation to date. Parallel to the evaluation of the settlement as “deep rural” in the literature (Öksüz, et al., 2014), it is difficult to say that Ataköy has an economic potential. It does not seem possible to say that the increasing tourism activity in the region in the last decade has had a significant impact on both the physical and economic development of the settlement. On the other hand, Ataköy is a settlement that is inward-looking, primarily consisting of local residents or individuals connected to the community. The buying and selling of land or buildings to outsiders or those not originally from the region is highly restricted and even closed off. Despite its rural character, economic limitations, and introverted social structure, Ataköy has experienced intense and increasing construction activity in recent years, primarily in the form of secondary housing. This trend makes the settlement atractive for the study.Unlike many villages in Turkey that are in danger of abandonment, Ataköy is a settlement where life continues with different intensity throughout the year. It is possible to say that migration in Ataköy has been an ongoing phenomenon from the beginning of the twentieth century to the present day (Yeni,2015:176-177). However, the phenomenon of migration never severs the connection of the local people with the settlement. Although there is a significant decrease in the resident population compared to the past (Table 1), families who migrate to the city return to the settlement as seasonal residents in the spring and especially in the summer months. This leads to fluctuations where the current population doubles or triples during the year.The socio-cultural change that the community has gone through as a result of migrations affects the built environment, and the effects of this change can be read at both the housing and settlement scale.

Firstly, all houses in the settlement were scanned using the built environment analysis in order to determine the housing type and housing use diversity. Videos featuring the entire settlement of Ataköy recorded by drone, shared on social media platforms (URL 2), as well as current cadastral maps obtained from the municipality, were utilized. All the residences in the settlement were classified into three groups—traditional, hybrid, and modern—based on their facade characteristics, building materials, and architectural formation, and were mapped onto the current cadastral plan (Fig.3). What distinguishes the group referred to as "hybrid" from the other two is that, while it employs contemporary building materials and construction techniques, it retains features similar to traditional houses in its facade and plan. To determine whether any of these groups is preferentially more prominent within the settlement, numerical data based on the building scale were utilized. Although each group exhibits qualitatively different characteristics, they have been associated with the period in which they were built, as they reflect the architectural features of their respective construction periods. Based on the information (Interviews with community members, 2023) that traditional housing production continued until the 1960s, traditional houses have been associated with the pre-1960 period. The first multi-storey apartment buildings were matched with the hybrid group until the 1990s, and with the contemporary housing group after 1990s, when low-rise/multi-storey apartments and detached houses started to become widespread. The fact that each of these groups reflects a specific period raises the question of whether there are distinct thresholds or breaking points in the settlement's development. In the second stage, the relationship between migration patterns and these breaking points within the settlement is examined.

3. Results

3.1. Current Adaptation Strategies and Housing Preferences

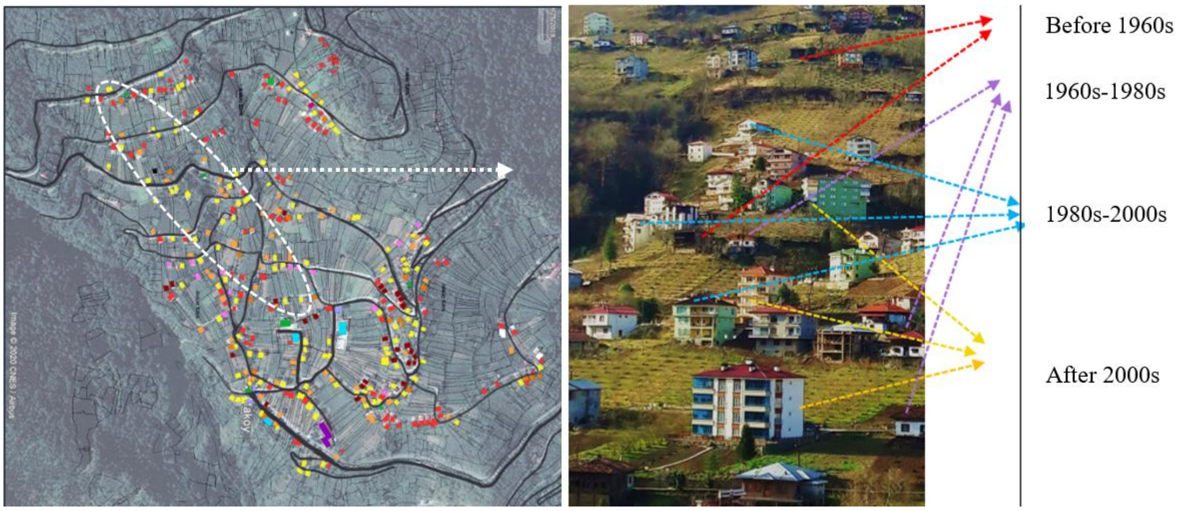

Fig. 3. On the left is the built environment analysis, on the right is a section containing part of the settlement

Table 2.Numbers and rates of housing types determined in Ataköy.

Traditioanal	Hybrid	Modern
170 houses (57 houses abondend)	73 houses	177 houses
%27(actively used)	%17	%42

According to the built environment analysis, contemporary residences were found to be the most numerous among a total of 420 houses (Table 2). It should be noted that this proportion would be even higher if determined based on the number of households rather than at the building scale. 33% of existing traditional housing is not used, and those that are used include interventions or additions of varying sizes. In addition, it was determined that 12 traditional houses were registered by state within the scope of protection and registration activities.

Recently, globalization and exposure to urban culture, along with increased mobility of individuals both in terms of communication and economy, have led to changes in lifestyle habits and preferences. This, in turn, has resulted in greater diversity in housing production and usage practices within the settlement. User preferences have come to the forefront, and factors such as limited land availability, fragmented ownership patterns, and the inability of traditional houses to meet current housing needs in their existing form have all contributed to this diversity.

In reference to Gür (1996) and Berry (1980), it is possible to identify three distinct strategies—reaction, adjustment, and abandonment—regarding the adaptation of community members to the existing housing and built environment (Table 3). Each of these strategies has its own unique dynamics, yet both directly and indirectly, they develop through traditional houses. The presence of the existing traditional rural fabric and the integrity of the built environment present various opportunities and threats. In the reaction strategy, although it does not meet current needs, it is aimed to benefit from the limited opportunities offered by the existing housing. Financial insufficiency, inheritance problems and short-term use are among the reasons for this strategy. In the arrangement, partial or comprehensive interventions or additions are made to existing houses in order to meet current needs. Partial intervention includes additions aimed at specialized space needs (such as wet areas, kitchens, etc.), as well as applications to extend the lifespan of the building, such as modifications to the façade, roof covering, or structural system. In a comprehensive intervention, while the main structural system remains intact, the entire building is renovated, with changes made to the façade character and spatial layout. In the abandonment strategy, the traditional house is either abandoned or demolished to make way for the construction of a contemporary dwelling. It is preferred due to reasons such as the inability to resolve inheritance issues, and the existing house lacking sufficient size, comfort, and privacy to accommodate the expanding family members. In the absence of sufficient land or financial resources to build a detached house suitable for each family, apartment buildings become an effective option. Apartments can be low-rise (maximum three floors) or high-rise (more than three floors), depending on the number of heirs and economic power. In most cases, the shift towards contemporary housing leads to the abandonment or demolition of traditional houses. (Fig. 4-5).

Table 2. Adaption Strategies

Strategies	Reaction (R) (adaptation to the current situation)	Arrangement (A) (modification/redesign)	Abondenment (AB) (relocation/destruction)
Outcome	Traditional House	Traditional House	Detach house, apartment

Fig. 4. When traditional housing is no longer sufficient to meet the needs of an expanding family and inheritance is divided, some heirs can opt to retain the traditional house, while others can prefer modern (detach/apartment) house, depending on the availability of suitable land.(1,2,3,4)

Fig. 5. The transformation of the same location before (on the left) and after 2000(on the right)

3.2. Socio-Cultural Changes Due to Migration and Their Effects on the Built Environment

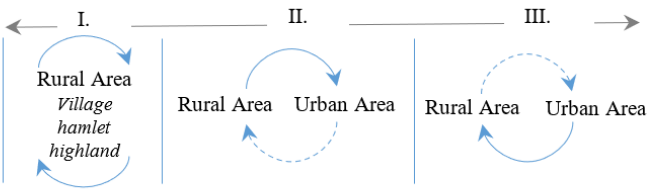

Fig. 6. Migration movements in Ataköy according to periods

In the pre-1960 period, due to limited climatic conditions and agricultural lands, compulsive seasonal migrations occurred between the village, hamlet, and highland within Ataköy. However, the limited and laborious nature of agricultural production, due to the conditions of the period, led the community to move towards cities after 1960 in search of a better life and future. This situation has led to a decline in the settlement's population over time and has altered the state of agricultural activities as the primary source of income. However, after the 2000s, with improvements in communication and transportation facilities and the increasing level of prosperity, it can be said that migration from cities to settlements continued. It can be said that this migration, unlike the seasonal migration that occurred before 1960 between village, hamlet, and highland, is now between cities and Ataköy(Fig.6). The settlement becomes a place of residence during the spring and especially summer seasons for community members who are bored with urban life and want to spend time in connection with nature.

4. Evaluation and Conclusion

Fig. 7. Two images reflecting the situation of the same location before 1960 and after 2000, taken from similar angles

Table 4. Periods and generations

← Villager / Urban Resident →

Traditional	Hybrid		Modern
Before 1960's	1960-1980	1980-2000	After 2000's

Although the local community's internalization of Ataköy as their homeland and the settlement's non-abandonment with a strong sense of place attachment is viewed as positive, demographic fluctuations which the population doubles or triples throughout the year (especially during the summer months), the rapid and unregulated construction activities driven by increasing housing demand, lack of an infrastructure system that can respond to a fluctuating population, the decline in sustainable agricultural activities, an increasing tendency toward consumption rather than production can be listed as some of the risks that threaten the settlement. On the other hand, population movements that have developed due to migration from the past to the present cause economic, social and cultural changes in the community, and these changes affect the built environment(Fig.7).

In contexts where the terms 'villager' and 'urbanite' are defined by lifestyle and daily practices (Ceylan& Somuncu 2018), the community can be characterized as 'villagers' in the pre-1960 period, when agriculture was the primary mode of production. Between 1960 and 2000, as contact with cities and urban production forms increased, the incomplete abandonment of rural production methods and lifestyles transformed the community into a 'hybrid' structure. After 2000, migration to urban by a significant portion of the population led to a decline in the rural population and resulted in a community composed predominantly of urban residents. This shift marked a transition from a rural-based identity to an urban-oriented social structure (Table 4), bringing about significant changes in value systems, lifestyle habits, expectations, and preferences.Individuals who turn to the settlement in search of a sense of belonging and an escape from urban chaos face challenges in adapting to the existing built environment and solve them with different strategies. However, these strategies cause various problems for the integrity of a healthy built environment and the traditional rural texture in the context of the settlement. One of the most prominent issues is that construction activities are often carried out not within a legal or regulatory framework, but rather—much like in the times when traditional lifestyles were dominant—within an informal system (or lack thereof) that relies on neighbourhood relations, customs, and mutual trust. It is evident that the traditional settlement pattern—characterized by houses of similar size and density, which did not obstruct each other's light or privacy and created a unique organic fabric in the past—can no longer be sustained due to today's changing needs and housing diversity. It is worrying that modern houses are being built independently of legal frameworks and without the guidance of expert-designed plans. However, after the Metropolitan Municipality Law there are licensed modern buildings in the settlement but their numbers are few. The second issue to be highlighted in this study is the community's lack of sensitivity towards traditional houses and the traditional settlement texture. Traditional houses can be easily demolished depending on the conditions or subjected to significant interventions in line with the needs. What is interesting here is that the intervention in the traditional house is based on the idea of 'preserving the ancestral home'. The lack of awareness and sensitivity regarding the fact that traditional housing and settlement textures are cultural heritage that need to be protected is seen as a significant issue or paradox, not only in Ataköy but also in most rural settlements across Turkey. What is even more interesting is that, in recent years, some individuals, upon hearing that their traditional houses might be registered through preservation efforts, prefer to demolish their house to make space for contemporary housing construction, in order to avoid undergoing the process. Most individuals whose traditional houses are registered face financial burdens and challenges in carrying out maintenance and repairs in accordance with legal obligations.Apart from its own unique context, Ataköy is an example that carries similarities in terms of changes, opportunities, and risks with many rural settlements in Turkey. In line with current dynamics, the boundaries between rural and urban areas are disappearing, and the common cultural system imposed by the new world order is simultaneously and multidimensionally infiltrating both rural and urban areas. Even though the unique and local identities of rural settlements have not yet vanished and the traditional architectural environment has not disappeared, it is crucial to conduct studies that highlight the value of traditional rural architectural heritage, raise societal awareness, and establish the necessary legal deterrents and incentives.

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Enhancing urban resilience: A comparative study of Dubai and Trabzon

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Abstract. This study addresses the challenges caused by climate change and cities' adaptation strategies and potentials based on their urban morphologies to enhance their urban resilience. Its primary focus is on the implementation of nature-based solutions and blue-green infrastructure.
A comprehensive case study and literature review examines the adaptation of landscape strategies and their integration into city plans. Focusing on Dubai, UAE, and Trabzon, Türkiye, due to their contrasting contexts, this study offers insights on broader sustainability applications.
Findings reveal both cities aim to apply these initiatives soon to prepare for climate adversities. Both Dubai's 2040 Masterplan and Trabzon's sustainability initiatives emphasize the implementation of United Nations Sustainable Development Goals (SDGs), which also complies with the Global Reporting Initiative (GRI)'s topic standards. These guidelines provide a framework for global strategy execution
This study provides a novel approach to ecological services integration into urban planning of Dubai and Trabzon as case studies, using their diverse context to offer unique insights into the practical application of these initiatives.
This research focuses on two case studies, offering detailed insights.Future research could expand by including a broader range of cities with different geographical and urban contexts.
Practical implications: The proposed initiatives can be used by policymakers and urban planners to embed ecological services into city plans, such as Dubai's 2040 Masterplan, thereby enhancing sustainability and urban resilience.
Enhancing urban resilience reduces financial losses from climate disasters. Additionally, we can expect to see more job opportunities in environmental management, construction, and tourism sectors.

Keywords: Urban Resilience; Blue-Green Infrastructure; Sustainability Initiatives; Nature-Based Solutions; Climate Change Adaptation

1. Introduction

1.1. General Background

The modern urban landscape in progressively facing various challenges due to climate change, society and economic changes, and environmental breakdown. Urban systems ability to absorb, recuperate and adjust against different natural shocks, is known as Urban Resilience. This concept has risen as the main principle in discussions of sustainable urban development (Sharifi & Yamagata, 2016).

The necessity of making cities resilience has transformed from theory and conceptualization into practical manuals and under globally acknowledged guidelines; particularly mandates set by United Nations Sustainable Development goals (SDGs) and the Global Reporting Initiative (GRI) Standards (GRI, 2021) as shown in Fig. 1.

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Fig. 1. United Nations Sustainable Development Goals (Pudke, 2023).

In this shifting environment, cities with varied climatic and morphological pattern must use localized resilience guidelines which is to answer their distinctive susceptibility while using the global standards as their basis. The implementation of landscape architecture and urban design strategies, especially with the use of nature-based solutions (NBS) and blue-green infrastructure (BGI), has gained recognition as a central tactic to enhance urban resilience.

1.2. Landscape Strategies for Urban Resilience

Urban resilience strategies are undergoing a transformative shift, moving from rigid grey infrastructure models toward adaptive ecological systems that are multifunctional and nature based. These solutions, green roofs, constructed wetlands, vegetated drainage systems, and permeable urban surfaces—are now acknowledged for their role in improving urban thermal control, stormwater mitigation, and biological diversity (Frantzeskaki, 2019). Additionally, blue-green infrastructure initiatives support integrated planning that connects hydrological management with green space design, thus enhancing the capacity of cities to withstand and adapt to hydrometeorological extremes.

Evidence from contemporary studies has demonstrated that landscape-driven interventions substantially improve urban adaptability across varying scales, ranging from small-scale neighborhood greening to expansive regional ecological corridors (Sharifi & Yamagata, 2016). However, the realization of these strategies is tightly interlinked with localized governance models, economic heterogeneity, and the existing spatial structure of the urban fabric, making tailored, context-sensitive implementation essential.

1.3. Aim of Research

This research conducts a comparative analysis of landscape-driven resilience strategies in two distinct urban environments: Dubai, characterized by arid desert conditions, and Trabzon, marked by a humid subtropical coastal climate. These contrasting ecological and governance settings present a valuable opportunity to explore how context-specific factors influence the implementation and performance of nature-based solutions for urban resilience.

The research aims to fulfill three core objectives:

- It investigates each city's urban form, governance structures, and vulnerability to climatic stressors.
- It evaluates ongoing landscape infrastructure practices through a SWOT framework, with particular attention to blue-green infrastructure and social inclusion.
- It identifies and compares how resilience strategies are embedded within the planning systems of both cities, whether already in place or projected for future deployment.

By weaving together theory, policy review, and empirical analysis, this study seeks to elucidate the real-world implementation dynamics of landscape-oriented resilience strategies. It further aims to distill actionable, transferable insights that can inform urban planning in similarly challenged ecological and socio-economic settings.

2. Material and Methods

This study aligns with established methodological expectations in resilience studies by employing a qualitative comparative case study framework. A triangulated review of documentary sources ensures both validity and conceptual integrity. The design supports a detailed interpretation of how policies, spatial plans, and governance structures interact in shaping landscape-based urban resilience efforts.

2.1. Data Sources and Scope

This study draws upon a critical review of official urban planning documents, long-term development strategies, and institutional sustainability frameworks. The primary sources informing this analysis are:

- Dubai Urban Master Plan 2040 (Dubai Executive Council, 2021),
- Trabzon İl Planlama 2015–2023 (Trabzon İl Planlama Müdürlüğü, 2015),
- GRI Sustainability Reporting Standards (GRI, 2021),
- UN 2030 Sustainable Development Goals (United Nations, 2015),
- And supplementary insights from literature on NBS and governance dynamics (Frantzeskaki, 2019; Sharifi & Yamagata, 2016; Pudke, 2023).

The case study method is justified given the stark ecological, spatial, and institutional distinctions between Dubai and Trabzon. These contrasting urban contexts present a compelling comparative lens for examining how landscape infrastructure planning is differentially articulated within resilience-oriented urban strategies

2.2. Methodological Phases

The methodology is systematically divided into three logically ordered and interdependent stages, each building upon the findings and processes of the preceding one:

Phase 1: Policy Content Analysis

In the first phase, a structured content analysis was conducted on urban plans at both municipal and regional levels to identify themes related to urban resilience. Using a combination of manual and software-assisted coding, the study captured recurrent policy signals in areas such as blue-green infrastructure, land use flexibility, ecological restoration, and spatial inclusivity. These documents were then mapped to the Global Reporting Initiative's (GRI) disclosures (GRI 2021:1; 2021:3) and evaluated against relevant Sustainable Development Goal (SDG) benchmarks.

Phase 2: SWOT Analysis Implementation

A SWOT matrix was applied to both cities to assess strategic conditions surrounding landscape infrastructure. This framework enabled classification into four categories:

- Strengths, such as available ecological resources and spatial capacity.
- Weaknesses, including planning or technical gaps.
- Opportunities, which represent possibilities for policy advancement and synergetic benefits.
- Threats, involving risks of environmental degradation, socio-political barriers, or economic constraints.

To accommodate contextual differences, separate SWOT matrices were developed for Dubai and Trabzon. This allowed tailored evaluations and facilitated cross-case comparison. Methodological reliability was ensured through procedural consistency testing methods, following guidelines established by Ozturk Saka & Erdogan (2022).

Phase 3: Cross-Case Comparative Synthesis

To synthesize both shared and divergent elements of resilience strategies in Dubai and Trabzon, a cross-comparative matrix was constructed. This matrix captured resilience indicators across urban form, planning instruments, participatory governance, and the institutional uptake of nature-based solutions (NBS). A systems thinking perspective guided the interpretation, revealing key interdependencies and areas of strategic intervention.

3. Results and Discussion

3.1. Policy Content Analysis

This phase centered on a structured review of urban policy documents and resilience strategies from Dubai and Trabzon, with the goal of identifying thematic elements related to nature-based solutions (NBS), landscape planning, and governance systems. Primary planning sources included the Dubai Urban Master Plan 2040 as shown in Fig. 2. (Dubai Executive Council, 2021) and Trabzon's 2015–2023 regional plan (Trabzon İl Planlama Müdürlüğü, 2015) as depicted in Fig. 3, alongside international sustainability frameworks such as the GRI Standards (GRI, 2021) and the UN Sustainable Development Goals (UN, 2015).

Fig. 2. Dubai Urban Master Plan 2040 (Dubai Executive Council, 2021).

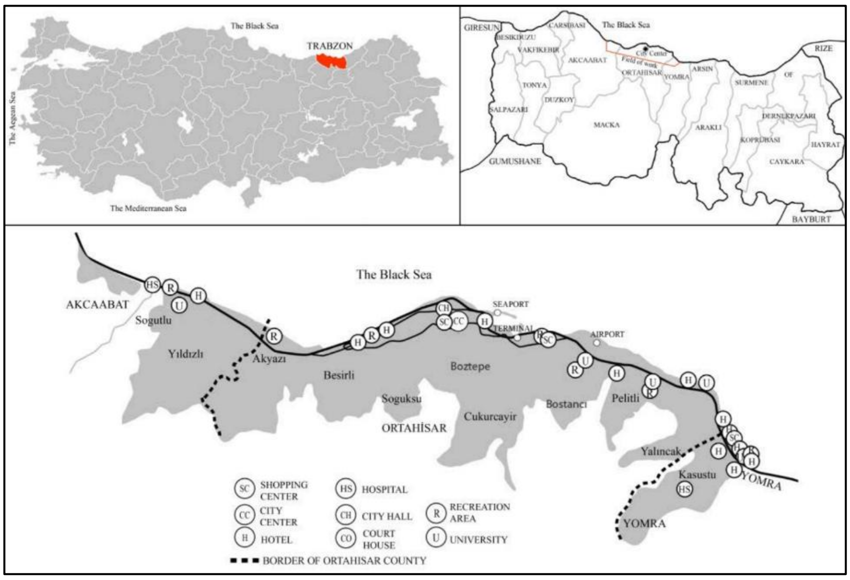

Fig. 3. Trabzon Urban Regions (Ünlü Öztürk & Türk, 2021).

This analytical framework addressed six dimensions: (i) institutional aspirations for resilience; (ii) spatial coherence of green and blue infrastructure networks; (iii) governance configurations and stakeholder inclusivity; (iv) climate adaptation policy; (v) restoration priorities; and (vi) mechanisms of participatory engagement. An iterative coding process enabled cross-comparative evaluation of how each urban policy environment aligns with resilience theory and global sustainability benchmarks.

Dubai's urban planning exhibits integrated vertical coordination, enabled by regulatory authority and financial capital to implement resilience policies across spatial tiers. In contrast, Trabzon’s policy framework centers on local-scale ecological coherence and traditional landscape practices, though it falls short in hierarchical consistency and international standardization. The analysis illustrates a bifurcated approach to resilience-building—Dubai mobilizes global indicators and centralized governance, whereas Trabzon fosters bottom-up, context-sensitive adaptation processes (Ozturk Saka & Erdogan, 2022).

3.2. The General Structure of the Case Cities

3.2.1. Dubai: Urban Morphology and Governance Context

Dubai, located in the hyper-arid environment of the Arabian Peninsula, has developed into an urban landscape marked by vertical expansion, controlled development clusters, and expansive infrastructure systems. This growth has occurred under a centrally coordinated governance model led by the Dubai Executive Council, operating through royal decrees and significant financial power (Dubai Executive Council, 2021). The city's spatial structure reflects its aim for global economic prominence, featuring dense commercial hubs, arterial transit infrastructure, and designated zones for tourism, industrial, and logistical activity.

High-profile urban districts such as Downtown Dubai and Dubai Marina underscore the city's prioritization of visually iconic, vertical urban forms. While large-scale greening efforts—ranging from afforestation to engineered islands—have been deployed to reinforce environmental narratives, the prevailing spatial logic remains automobile-dependent. Fragmentation of green space networks and limited walkable environments persist as key urban design challenges.

Dubai faces harsh climatic conditions characterized by intense evapotranspiration, scarce rainfall, and regular dust storms, all of which heighten environmental stress. In response, the city's resilience strategies have emphasized water-sensitive planning, efficient desalination, and reliance on solar technologies. Institutional frameworks are further strengthened through alignment with global standards such as the GRI (2021) and the SDGs (United Nations, 2015), Dubai's SWOT analysis is as shown in Fig. 4.

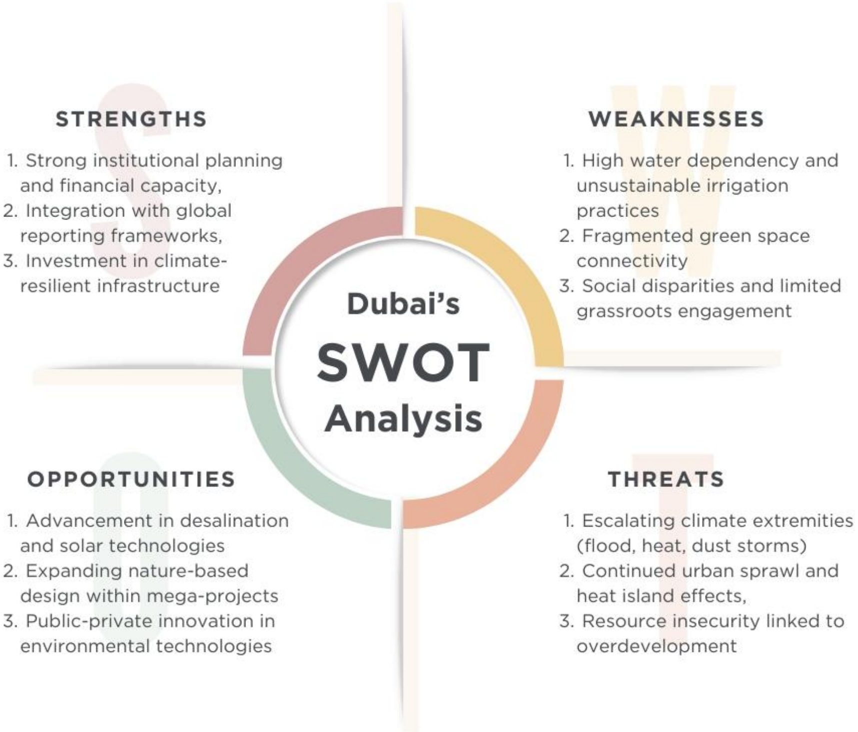

Fig. 4. Dubai's SWOT analysis.

3.2.2 Trabzon: Spatial Structure and Institutional Complexity

Trabzon, positioned on Turkey's northeastern Black Sea coast, exemplifies a divergent urban condition characterized by hilly terrain, coastal adjacency, and an organically formed settlement network. In contrast to Dubai's master-planned urban modernism, Trabzon's urban structure reflects a layered evolution shaped by geography and longstanding cultural and historical processes (Trabzon İl Planlama Müdürlüğü, 2015).

Trabzon exhibits a compact spatial form in its historic center, which gradually becomes more fragmented and expansive in the peripheral zones as housing developments extend into hilly terrains. Industrial and agricultural uses are often situated close to one another, raising land-use coordination challenges. Vital ecological features, including rivers and wetlands, are integral to the city's landscape identity but face pressures from urban sprawl and weak zoning enforcement.

Trabzon's governance framework is characterized by a layered structure that includes municipal, regional, and national authorities. While less financially independent and not strongly integrated into global resilience reporting systems relative to Dubai, Trabzon's planning documents prioritize key environmental strategies such as conserving ecological corridors, ensuring slope stability, and managing coastal zones. These strategies are enriched by the use of traditional knowledge and active local stakeholder participation (Ozturk Saka & Erdogan, 2022), the SWOT analysis of Trabzon is showcased in Fig. 5.

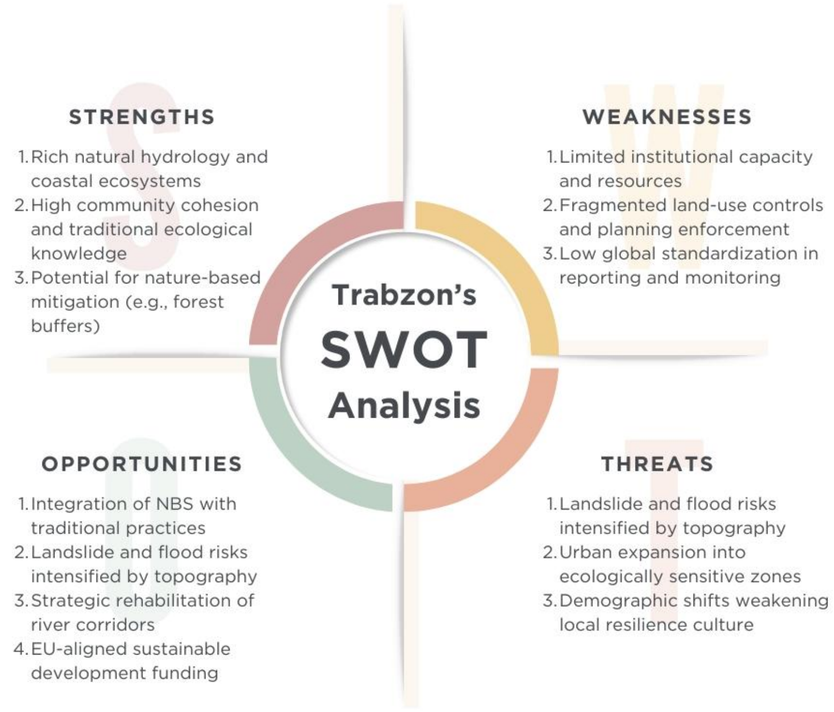

Fig. 5. Trabzon's SWOT analysis.

3.3. Landscape-Based Resilience Systems

3.3.1. Blue-Green Infrastructure

Blue-green infrastructure (BGI) is central to resilience planning in both Dubai and Trabzon. In Dubai, the strategy focuses on engineered landscapes such as constructed wetlands, artificial lakes, and delineated green zones, as detailed in the Dubai Urban Master Plan 2040 (Dubai Executive Council, 2021). These systems are designed to counteract the impacts of intense urbanization and extreme climate conditions like heat and aridity. The city's BGI is executed through hierarchical, top-down planning frameworks, bolstered by coordinated investments from state entities and private sector actors.

Trabzon approaches BGI by leveraging its rich natural environment—streams, wetlands, and forested slopes serve as the foundational elements. Its humid climate and rugged terrain create dual dynamics: abundant rainfall supports dense vegetation but also increases susceptibility to surface flooding and erosion. This necessitates BGI that functions in tandem with hydrological systems (Trabzon İl Planlama Müdürlüğü, 2015). Compared to Dubai's formalized and top-down model, Trabzon's BGI is less structured but deeply embedded within traditional land practices and organic ecological management.

Dubai's BGI framework is notable for its scale and forward-looking vision, yet it is heavily engineered and demands substantial upkeep. In contrast, Trabzon benefits from an inherently resilient ecological base that supports more passive, low-energy BGI systems, though its effectiveness is limited by weak institutional coordination and ad hoc implementation. These differences highlight the importance of tailoring BGI strategies to local climatic, topographic, and governance contexts.

3.3.2 Social Dimensions of Urban Resilience

The social structure of a city plays a decisive role in shaping how BGI is adopted, governed, and sustained by communities. In Dubai, the diverse demographic profile introduces both challenges and opportunities. On one hand, the city's multicultural makeup drives the need for multifunctional, inclusive public spaces that address varied cultural, economic, and visual expectations. This is evident in the implementation of walkable urban districts, adaptable park designs, and green infrastructure embedded within residential developments (Awad & Jung, 2022). However, Dubai's socio-economic stratification, particularly affecting migrant labor groups, limits equitable participation in planning and diminishes the resilience potential of such systems.

Trabzon exhibits a socially cohesive population shaped by historical continuity and territorial rootedness, which translates into strong environmental stewardship, particularly on the rural-urban fringe. This social cohesion fosters resilience through communal networks and participatory cultural norms (Trabzon İl Planlama

Müdürlüğü, 2015). Yet, such informal strength can be seen as a weakness as it will cause the initiatives lack diversity.

In summary, Dubai's socially heterogeneous landscape enables ambitious urban innovation, but challenges remain in ensuring inclusive stakeholder engagement. Trabzon, with its cohesive social networks, supports grassroots resilience efforts, though its systems lacks variety when taking initiatives. Addressing these limitations demands context-specific planning: Dubai must strengthen inclusive representation mechanisms, while Trabzon should focus on enhancing it's heterogeneous outlook.

3.3.3 Nature-Based Solutions Integration

In urban planning, nature-based solutions (NBS) refer to the intentional use of ecological systems to address challenges such as heat, flooding, and biodiversity loss, while also providing economic and social benefits. Dubai's approach to NBS emphasizes large-scale ecological interventions, including desert greening, the introduction of salt-tolerant urban trees, and the stabilization of coastal dunes with bio-barriers (Dubai Executive Council, 2021). These efforts are part of the broader Dubai 2040 vision and are tracked through GRI sustainability indicators to ensure comprehensive ESG performance reporting (GRI, 2021).

Trabzon's nature-based strategies diverge from technocratic planning models, evolving instead through organic integration with cultural land practices. Examples include community-managed rainwater capture systems, terraced cultivation for slope erosion control, and the landscape use of native plant species (Trabzon İl Planlama Müdürlüğü, 2015). Though informal and often absent from formal policy instruments, these interventions embody adaptive, place-specific knowledge embedded in human-ecological interdependence.

Dubai and Trabzon diverge fundamentally in their approach to nature-based solutions, particularly regarding scale and institutionalization. Dubai's system is structured through formal governance instruments and prioritizes centralized, resource-intensive interventions. Conversely, Trabzon's strategy is diffuse, adaptive, and rooted in localized environmental practices. Despite these structural differences, both models reinforce the necessity of context-sensitive NBS frameworks—those which align with governance modalities, urban configuration, and sociocultural traditions to support resilient urban futures.

3.4. Urban Resilience Strategies and Discussion

Although both Dubai and Trabzon embed resilience within their landscape frameworks, their strategic orientations diverge across several dimensions. Dubai operates within a highly formalized and centrally coordinated governance structure that aligns with global standards. In contrast, Trabzon's resilience efforts are more fragmented, grounded in locally adaptable knowledge systems and responsive to socio-ecological conditions.

3.4.1. Dubai's Strategic Approach to Resilience

Dubai's resilience framework is embedded in the Dubai Urban Master Plan 2040, which envisions sustainability as a central pillar of urban development. The strategy prioritizes enhanced liveability via pedestrian-friendly districts and accessible green areas, the development of green corridors to foster ecological connectivity, investments in renewable energy and efficient water use, and transparent sustainability reporting aligned with international standards such as the GRI (GRI, 2021).

Nature-based solutions in Dubai are deployed through a technologically advanced and capital-intensive framework. These include engineered wetlands to manage runoff, vertical forest systems for microclimate regulation, and biosaline cultivation techniques to address water scarcity (Dubai Executive Council, 2021). While structurally innovative, the approach is marked by limited civic involvement, which may hinder social acceptance and reduce the flexibility required for long-term urban resilience.

Although challenges persist, Dubai excels in unifying its urban design, climate adaptation strategy, mobility planning, and economic development under a coherent framework. Its alignment with global sustainability agendas and strong international positioning make it a prominent experimental site for resilient infrastructure in hyper-arid regions.

3.4.2. Trabzon's Contextual and Community-Based Strategies

Trabzon employs a context-sensitive resilience model grounded in ecological awareness and spatial limitations. Its approach, though less formalized, incorporates community knowledge and adaptive land-use responses. Notable strategies include the stabilization of slopes using forest retention and terracing, watershed rehabilitation to mitigate hydrological hazards, and community-anchored greening initiatives informed by long-standing local traditions (Trabzon İl Planlama Müdürlüğü, 2015).

The nature-based strategies adopted in Trabzon emphasize socio-ecological resilience, favoring minimal-impact interventions, community-driven management, and the adaptive reuse of landscape assets. Although these practices are not formally benchmarked to global indicators such as the GRI or SDGs, they demonstrate high congruence with local cultural values and spatial realities—an important condition for durable resilience in smaller cities.

Trabzon's resilience efforts are constrained by key institutional barriers—namely, a lack of standardized planning frameworks, restricted budgets, and limited monitoring capacity. These limitations impede the scalability and transferability of locally successful initiatives. Even so, Trabzon provides a compelling example of how resilience can emerge from community-based knowledge, ecological synergy, and decentralized governance structures.

3.5. Comparative Discussion

The comparative analysis highlights distinct models of urban resilience:

- Dubai's approach is marked by formalized planning, large-scale engineered infrastructure, and top-down governance mechanisms aligned with international benchmarks.
- Trabzon emphasizes localized ecological insight, adaptive and incremental planning processes, and strong community participation in shaping resilient outcomes.

These two models of urban resilience illuminate broader theoretical contrasts—between rigidity and adaptability, technocratic control and ecological responsiveness, and top-down coordination versus participatory governance. Crucially, each framework offers unique operational strengths while also revealing its contextual limitations.

Dubai's resilience model demonstrates efficiency in infrastructure rollout and achieves defined environmental metrics, yet its limited local engagement and top-down implementation may compromise adaptability and social inclusion. Trabzon, on the other hand, prioritizes ecological fit and participatory processes, though its lack of fiscal and institutional strength inhibits replication and system-wide expansion.

This discussion highlights that resilience cannot be universally prescribed. It must be crafted through an assemblage of context-sensitive strategies that align environmental systems, built infrastructure, and social dynamics. To be effective, future frameworks for resilience must aim to:

- Enable productive interfaces between top-down governance and community-driven experimentation.
- Link local action plans to international reporting frameworks such as GRI or the SDGs, while maintaining fidelity to indigenous and contextual knowledge systems
- Construct infrastructural systems that are both ecologically adaptive and socially embedded.

Dubai and Trabzon offer contrasting yet synergistic resilience logics. The integration of Dubai's advanced infrastructural planning and formal governance with Trabzon's participatory ethos and ecological embeddedness presents a compelling composite model. Such hybridization holds the potential to guide next-generation urban resilience strategies that are both structurally robust and socio-culturally attuned.

4. Conclusion and Suggestions

4.1. Conclusion

By comparing Dubai and Trabzon, this study confirms the centrality of landscape-focused planning in shaping resilient responses to climate stress, urban growth, and ecological transformation. Despite shared use of nature-based solutions, their approaches differ sharply—shaped by geography, institutional frameworks, cultural practices, and divergent urban development paths.

Dubai's approach to resilience is grounded in centralized governance and strategic urban design, strongly tied to global benchmarks such as the GRI and SDGs (GRI, 2021; UN, 2015). This model enables the deployment of engineered blue-green infrastructure and technologically intensive nature-based solutions, offering measurable and system-wide results. However, the reliance on artificial ecosystems, substantial energy inputs, and limited grassroots involvement raises questions about the city's long-term adaptability and ecological legitimacy in the face of dynamic climate challenges.

Trabzon presents a resilience paradigm centered on decentralization, cultural continuity, and ecological embeddedness. Through community-led efforts, the city advances small-scale ecological restoration and fosters cohesion at the neighborhood level. Though underrepresented in global reporting systems, this model demonstrates the viability of locally adapted, participatory resilience-building. However, policy fragmentation, fiscal limitations, and the absence of institutional mechanisms for broad replication hinder its scalability.

A direct comparison between Dubai and Trabzon surfaces several key takeaways that illuminate how urban resilience strategies are shaped by context, capacity, and governance orientation:

- Resilience is context-sensitive by necessity: Strategies must reflect the socio-ecological specificity of place—factoring in biophysical conditions, institutional dynamics, and cultural patterns. When implemented in a vacuum, generalized or top-down approaches risk inefficiency, social disengagement, and ecological mismatch.

- BGI must be contextually responsive: Successful blue-green infrastructure should be adapted to fit local conditions—including urban form, climate variability, and governance systems—rather than relying purely on engineered complexity. The contrast between Dubai's constructed wetlands and palm groves and Trabzon's river rehabilitation and terraced slopes illustrates the importance of situational appropriateness.
- Social inclusion is an underdeveloped pillar of resilience: Although ecological adaptation is prioritized in both Dubai and Trabzon, the social components—particularly participation, cultural relevance, and equity—receive insufficient attention. Effective resilience planning must increasingly center on inclusive engagement and community empowerment.
- NBS must be embedded in urban systems: For nature-based strategies to be effective, they must operate within the logic of comprehensive planning—connecting with transport, housing, water, and energy systems. Fragmented application risks underperformance and system inefficiency.
- Global goals require local translation: The value of standards like SDGs and GRI lies not in adoption alone, but in meaningful implementation through localized planning, budgeting, and enforcement. Dubai reflects alignment through formal systems; Trabzon presents the need for adaptive, culturally embedded interpretation.

4.2. Suggestions

Drawing from the comparative conclusions outlined above, the following policy and research recommendations are offered to inform future urban resilience planning and implementation:

- Synthesize centralized formality and decentralized adaptability: Resilience models should integrate Dubai's structured, globally aligned planning systems with Trabzon's locally grounded, participatory approaches to support comprehensive and scalable resilience design.
- Support local institutional development: To enable cities like Trabzon to scale their resilience strategies, focused investment is needed in governance infrastructure, planning skillsets, and mechanisms for international knowledge exchange.
- Promote inclusive planning platforms: To enhance resilience outcomes, both cities must invest in participatory mechanisms such as community mapping exercises, collaborative design processes, and citizen science initiatives that allow residents to actively shape their urban environment.
- Institutionalize dynamic assessment systems: To ensure accountability and learning, cities should implement ongoing monitoring frameworks that evaluate both ecological function and social inclusivity of BGI and NBS projects, using a blend of international benchmarks and locally tailored indicators.
- Enable cross-city learning ecosystems: Cities operating under differing environmental and institutional regimes should participate in global resilience coalitions to co-develop and share technical frameworks, policy instruments, and context-sensitive design practices for landscape-led adaptation.
- Advance durable ecological integration: Urban resilience requires the reclassification of ecological infrastructure as a long-term investment priority. This entails institutional protection, sustained funding, and incorporation into formal urban development strategies.

4.3. Future Research Directions

To strengthen the evidence base for urban resilience, future research should:

- Conduct empirical fieldwork assessing the long-term ecological and social outcomes of BGI and NBS projects in diverse contexts.
- Explore how emerging digital technologies can support adaptive and real-time landscape management
- Investigate how issues of climate justice influence equitable access to resilient infrastructure
- Broaden comparative analysis to include smaller cities and informal settlements that often experience acute but underexamined resilience deficits.

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The impact of migration on spatial organization and sociological change: an analysis of cognitive mapping in Yomra district, Trabzon province

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Abstract. The transformations experienced by cities throughout history are not limited to their physical structures but are also evident in their sociological dimensions. In periods of significant migration, the cultural structures of individuals in affected areas have also undergone changes alongside the transformation of settlement patterns. The phenomenon of migration has multifaceted impacts, influencing individuals' residential preferences and the developmental cycles of cities. Study aims to demonstrate that the effects of migration on spatial transformations extend beyond the physical dimension, exploring how individuals perceive these changes and the influence of settlement patterns on urban dynamics. Changes in real estate values and their influence on residential preferences were investigated through face-to-face and online surveys conducted with property owners in the Yomra district. The mobility in real estate acquisitions before and after migration was analyzed to reveal how this mobility reflects changes in urban space and individual perceptions. Using this method, the shift in spatial perception from Trabzon city center to Yomra district and the social and physical impacts of preferred new areas on individuals are examined. Cognitive mapping serves as an effective tool to understand individuals' spatial memory and perceptual changes. The primary factors influencing migrants' preferences are identified as increases in real estate values and changes in the social structure. By addressing both the physical and social effects of migration, research underscores the importance of multidimensional analysis in understanding the impact of migration on urban spatial organization.

Keywords: Spatial impact; Perception of space; Migration, Real estate mobility analysis

1. Introduction

Throughout history, cities have undergone significant transformations not only in their physical structures but also in their social fabrics. One of the most fundamental and persistent drivers of these transformations is the phenomenon of migration. Migration is a multidimensional process that reshapes not only the spatial mobility of individuals but also the physical organization, social composition, and cultural identity of urban areas (Castles, de Haas, & Miller, 2014; İçduygu, 2020). Migration movements, whether voluntary or forced, particularly those directed from rural to urban areas or from city centers to peripheries, can lead to outcomes such as spatial sprawl, class-based segregation, and social inequality. In this context, migration is not merely a demographic movement that expands the physical boundaries of cities; it is also a dynamic force that transforms individual-level perceptual processes such as spatial perception, urban memory, sense of belonging, and wayfinding behaviors. Especially for individuals whose settlement preferences change due to migration, meaningful spaces, central areas, and public structures within the city are redefined, directly affecting their levels of urban belonging and modes of social interaction (Tuan, 1977; Lynch, 1960).

The tendency toward settlements distant from city centers not only generates new residential areas but also causes a rupture in individuals' emotional and cognitive connections with the city. In this regard, the province of Trabzon offers a particularly compelling case. Located in Turkey's Black Sea region, Trabzon has recently become a major attraction for international migrants, particularly those from the Middle East and the Caucasus. Due to the city's coastal morphology, limited housing supply, and density in central areas, the incoming population tends to move toward surrounding districts. Within this context, Yomra district stands out due to its rapid spatial development, demographic transformation, and significant increases in real estate values. Over the past decade, notable trends such as population growth, development pressure, rising housing demand, and changes in the social composition have rendered Yomra a unique case for analyzing spatial transformation.

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The primary objective of study is to analyze the impacts of migration on urban space not only at the physical level but also through individuals' spatial perceptions, wayfinding practices, and levels of social belonging. The study reveals the perceptual shift of urban centers resulting from migration flows from city centers to peripheral districts and evaluates the multidimensional effects of this process on individual/public space perception, urban memory, and social integration. Within the scope of the research, the migration movements from Trabzon's city center toward the Yomra district have been taken as the basis, and the study interrogates the impacts of these movements at both physical and perceptual levels. Yomra district was selected due to several factors: the rapid pace of housing development following migration, the increasing interest of international investors, significant shifts in real estate market values, and the observable diversification of the social structure. Moreover, Yomra's geographical position, lying along the eastern coastline, plays a critical role within the broader macroform expansion of the city of Trabzon, further enhancing the regional relevance of the study. In this context, the research adopts a multi-layered methodological approach, focusing on data collection at both spatial and perceptual levels. Initially, demographic and economic data specific to the Yomra district within the province of Trabzon were analyzed, assessing trends over the past decade, including population growth, rising housing demand, and observable transformations in the social fabric.

As part of the fieldwork, surveys were conducted through online methods with homeowners residing in the Yomra district to investigate their housing acquisition preferences, spatial settlement decisions, and the social and economic factors influencing these decisions before and after the migration process. One of the most distinctive aspects of study is the use of the cognitive mapping method. Through this approach, the study examined how participants' spatial perceptions transformed in response to the settlement shift from Trabzon's city center toward Yomra and visualized the phenomenon of "perceptual center displacement" as reflected in participants' mental maps. In this respect, the study demonstrates that migration affects not only the production of physical space but also transforms individuals' cognitive, emotional, and experiential relationships with the city through a multidimensional process. By employing this perspective, the research addresses the relatively underexplored relationship between migration and spatial perception in the existing literature, offering both theoretical and empirical contributions. Thus, the study advances the understanding of migration-induced spatial dynamics by providing an original and comprehensive framework.

2. Literature review

The phenomenon of migration is a multilayered process that entails not only physical expansion in the spatial organization of cities but also class-based, cultural, and perceptual segregation (Harvey, 2012). In particular, new residential areas emerging on the urban periphery are often characterized by the concentration of low-cost housing production, limited infrastructure services, and the clustering of socio-economically vulnerable groups (Erder, 1996; UN-Habitat, 2020). Although such peripheral zones gradually develop their own internal social and economic patterns, individuals moving away from city centers frequently face significant barriers in accessing essential urban services such as public transportation, healthcare, education, and public spaces (Bayırbağ, 2010). In this context, migration becomes not merely a spatial relocation but a process through which intra-urban inequalities are reproduced.

Studies focused on the Black Sea Region have demonstrated that Trabzon and its surrounding areas have undergone significant spatial transformation processes in recent years due to increasing international migration (Yılmaz & Durmuş, 2021). Specifically, the district of Yomra has emerged as a micro-geography in which this transformation becomes particularly visible, reflected through new housing developments, land use changes, and shifts in social structure. Migrants' housing preferences tend to favor peripheral districts that offer more affordable options compared to central areas, a trend that accelerates spatial segregation and gives rise to cultural, class-based, and perceptual boundaries between local populations and migrant communities (Kaya & Kentel, 2005; Cernea & Maldonado, 2020). It is well-established in the academic literature that such boundaries shape not only social relations but also individuals' urban experience and their sense of spatial belonging. Space should not be regarded merely as a physical entity; rather, it must be understood as a multilayered construct shaped by individuals' everyday practices, experiences, memories, and navigational behaviors. Yi-Fu Tuan's (1977) distinction between "space" and "place" underscores the emotional and cognitive bonds individuals establish with their environment. In this regard, experiencing the environment not just as a neutral "space" but as a meaningful "place" plays a central role in the formation of social belonging and urban memory. As Kevin Lynch (1960) emphasized in his seminal work *The Image of the City*, the way individuals perceive, remember, and mentally organize the city directly influences their spatial experience. Symbolic structures, paths, edges, and nodes within the urban landscape serve as key reference points in individuals' mental maps. Cognitive mapping, a method introduced by Downs and Stea (1973), provides a powerful analytical tool for understanding how people perceive urban spaces, how they engage with them, and which areas they find meaningful. This technique makes it possible to visualize individuals' processes of orientation, attachment, and symbolic association within the urban fabric. Migration processes, particularly in the context of urban peripheries, are not solely limited to population growth or spatial dispersion but also entail deep transformations in land use, housing demand, and socio-spatial relations. In this regard, Tanrıvermiş (2022), in her contribution to the volume edited by Arda Özkan, emphasizes that internal migration in Turkey—especially toward secondary urban centers and coastal districts—triggers significant structural shifts in local real estate markets and accelerates the redefinition of urban boundaries. Her analysis highlights that migration-induced housing pressure frequently results in the proliferation of unplanned settlements, increasing the need for inclusive and adaptive planning tools that consider not only physical infrastructure but also the social integration of newcomers. The findings from Yomra reflect similar dynamics, where migration has led to not only a quantitative expansion of the housing stock but also to qualitative changes in spatial perception, access to services, and property ownership patterns. Montello (2002) further argues that cognitive maps reflect not only personal memory traces but also collective perceptions and representations of the city. In this context, spatial changes driven by migration also imply a restructuring of individuals' mental maps.

In particular, migration from central urban areas to peripheral districts alters individuals' urban perceptions and daily spatial routines. As people move away from iconic urban landmarks, their perceptions of new residential zones are increasingly shaped by practical criteria such as housing prices, accessibility, and perceived safety (Canter, 1977). This shift leads to a weakening of "visual memory" in cognitive maps, where distinctive and symbolic central images are replaced by anonymous and repetitive built environments. Consequently, along with the physical transformation of space, individuals' perceptual bonds with that space also undergo a profound transformation. The theoretical and conceptual framework derived from the literature review is directly related to the analytical methods employed in this study. Table 1 summarizes multidimensional themes concerning the spatial impacts of migration and links them to key studies selected from both national and international literature. These themes also shed light on the spatial transformations observed in Yomra District, including migration-induced shifts in perceptual centers and changes in urban identity. The processes of physical expansion, spatial segregation, and class-based differentiation triggered by migration influence not only housing policies but also affect transportation, social services, and social integration dynamics. Mental images and wayfinding behaviors developed by individuals in relation to new settlement areas have been analyzed through the method of cognitive mapping. This has made it possible to visualize both physical and perceptual spatial ruptures. Furthermore, the table attempts to relate the frequently emphasized concepts in the literature—such as the distinction between "place" and "space" (Tuan, 1977) and the influence of urban imagery on individual memory (Lynch, 1960)—to the case of Yomra. This approach aims not only to integrate theoretical knowledge but also to provide a robust basis for evaluating the local impacts of migration.

Table 1. Literature themes in the context of migration, spatial perception, and urban transformation

Theme	Key Concepts	Seletced Representative References	Relation to the Yomra Case
Migration and Urban Sprawl	Physical expansion, spatial segregation, rural-peripheral settlements	Harvey (2012); Erder (1996); Bayırbağ (2010)	Increasing housing development in Yomra as a peripheral district due to migration
Migration and Socio-Spatial Inequality	Class-based segregation, vulnerable groups, infrastructure access	Yılmaz & Durmuş (2021); Kaya & Kentel (2005)	Segregation between migrants and locals, disparities in service access, and social distancing
Sociological Construction of Space	Space-individual relationship, sense of belonging, experiential meaning	Tuan (1977); Canter (1977)	Lack of attachment and perceptual disconnection in newly developed migrant housing areas
Urban Perception and Wayfinding	Urban image, mental landmarks, cognitive imagery	Lynch (1960)	Perceptual shift from Trabzon city center to Yomra as the new mental reference point
Cognitive Mapping Method	Mental maps, individual orientation, social perception maps	Downs & Stea (1973); Montello (2002)	Visualization of migrants' urban perception and weak symbolic ties to the new environment
Perceptual Change through Migration	Shifting perceptual centers, urban memory, anonymization	Canter (1977); Tuan (1977)	Emergence of Yomra as a new perceptual center; increasing neutrality compared to historic core

3.Research methodology

Given that research aims to examine the effects of migration on urban organization at both spatial and perceptual levels through a multilayered perspective, a mixed-methods approach has been adopted. In this context, both quantitative data analyses and qualitative research techniques were employed simultaneously, allowing for an integrated assessment of the physical-spatial impacts of migration alongside individuals' perceptions of the urban environment. The methodological framework is grounded in four primary data sources and analytical techniques. In the first phase of the study, population growth trends, migration dynamics, and housing market activity in the Yomra district were analyzed using data from the Address-Based Population Registration System (ADNKS) and housing sales statistics published by the Turkish Statistical Institute (TUİK). This analysis covered the period from 2015 to 2024 and included key indicators such as population growth rates, the number of construction permits and property transfers, data on newly registered taxpayers related to property acquisition (sourced from the Trabzon Tax Office Directorate), and average square meter housing prices. These datasets were evaluated through comparative tables to capture temporal trends and spatial implications.

To enable the integration of qualitative and quantitative data, a survey was conducted with 156 homeowners (total population of approximately 50,339) residing in the Yomra district. The questionnaire included both multiple-choice and open-ended questions designed to assess:

- Housing acquisition preferences before and after migration,
- Social and economic factors influencing settlement decisions,
- Perceptions of accessibility, safety, and satisfaction with infrastructure,
- Sense of belonging and evaluations of urban image.

The surveys were administered online. The data were analyzed using the SPSS software, where descriptive statistics were presented, and cross-tabulations were used to reveal the relationships between demographic variables and housing perceptions.

One of the unique aspects of this study was the use of cognitive mapping, which aimed to uncover participants' mental representations of urban space. Respondents were asked to draw a mental map that included both the Trabzon city center and the Yomra district. These drawings were analyzed

- *Wayfinding references and symbolic structures related to the city center,*
- *Levels of attachment to new residential areas,*
- *Transportation networks, public buildings, and social hub* based on the following elements.

The maps were coded under three thematic categories—identified structures, environmental relationships, and symbolic meanings—using content analysis methodology. They were then digitized and evaluated comparatively with the housing acquisition data to identify spatial patterns within the mental maps. This study employed a multilayered methodological approach by combining quantitative and qualitative data collection techniques to evaluate the impact of migration on the urban environment and social structure.

Within the scope of this research, official statistical data and field-based findings were integrated to simultaneously analyze the demographic, economic, spatial, and perceptual dimensions of migration. Population data obtained from the Turkish Statistical Institute's Address-Based Population Registration System (ADNKS) covering the period from 2015 to 2023 were used to examine key indicators such as net migration, annual population growth, and settlement distribution in Yomra district. The population of Yomra increased from approximately 38,150 in 2017 to 47,283 by the end of 2022. These figures not only demonstrate the rapid transformation experienced by the region due to inward migration, but also provide a solid foundation for spatial analyses. Housing production and property transfer data—such as building permits and title deed transactions—were evaluated using combined datasets from TUIK and the General Directorate of Land Registry and Cadastre (TKGM). Based on these datasets, the annual increase in housing demand and construction activities following migration was assessed. The rising number of building permits and the acceleration of real estate transactions were examined to reveal the direct impact of migration on the production of physical urban space.

This multilayered methodological framework enables the analysis of not only the quantitative and spatial impacts of migration, but also individuals' perceptual and experiential responses. The diverse range of data collected—including population statistics, land cover analyses, property records, and mental maps—has facilitated a comprehensive evaluation of the physical, economic, social, and psychological dimensions of migration. In doing so, the study proposes an interdisciplinary and in-depth assessment model, offering an original contribution to the fields of urban planning, urban sociology, and real estate studies. By considering not only patterns of physical growth but also the ways in which space is experienced and remembered, the research provides a holistic understanding of migration-induced urban transformation.

4.Migration-induced mobility in the real estate market

The rapid population growth and real estate activity observed in the Yomra district in recent years provide a compelling case for understanding the localized manifestations of this multilayered relationship. The data analyses conducted in this context demonstrate that migration does not merely respond to a temporary housing need, but also fundamentally transforms the structure of housing demand, permitting processes, and property transactions (Yılmaz & Durmuş, 2021; TUIK, 2024). As presented in Table 2, the datasets used were directly integrated into the analytical framework and illustrate how Yomra has experienced intense real estate mobility as a result of increasing migration flows over the past decade

A significant increase has been observed in both housing sales and property ownership transfers, particularly after 2016. These increases (Table 3) are directly related to the settlement tendencies of the incoming migrant population. According to housing sales statistics provided by the Turkish Statistical Institute (TÜİK), while the average annual increase in housing sales across the Trabzon province was approximately 8%, this rate exceeded 20% in the Yomra district during the same periods. This trend indicates a shift in settlement preferences away from the urban core and suggests that Yomra has emerged as a new urban attraction center. Data from digital real estate platforms reveal that the average square meter price, which was 2,800 TL in 2015, rose to 14,200 TL by

2024. This sharp increase in property values cannot be explained solely by economic factors; rather, it must also be understood in the context of socio-spatial dynamics such as the production of high-quality housing tailored to the migrant profile and the intensification of urban land speculation. When the increase in housing prices in Yomra is compared with the national Housing Price Index (HPI)–based estimations, it becomes evident that the growth rate in Yomra significantly surpasses the national average. This discrepancy cannot be attributed merely to general economic inflation or market conditions; instead, it highlights the influence of migration flows, demand for high-standard housing, and investment-driven speculative pressures. The figures presented for the 2015–2019 period illustrate the initial divergence, which has become even more pronounced in subsequent years. These findings strengthen the study's argument that migration has had a direct and substantial impact on the local housing market (CBRT, 2024).

Table 2. Data sources and their use within the scope of the study

Indicator	Data Source	Purpose
Annual Number of Housing Sales (Yomra)	TÜIK	Analyzing supply-demand dynamics following migration
Annual Population Growth (Trabzon/Yomra Comparison)	TÜIK	Identifying spatial concentrations of migration
Average Housing Price Change (2015–2024)	Endeksa/EmlakJet	Visualizing property value increases
Number of Title Deed Transfers	TKGM	Indicating property transaction activity
Increase in Tax Declarations	Trabzon Tax Office	Supporting findings on migrant property ownership concentration

Table 3 Comparative housing market data for Yomra, Trabzon, and Turkey (2015–2024)

Year	Yomra Avg. Price per m² (TRY)	Yomra Annual Sales Growth (%)	Trabzon Annual Sales Growth (%)	Turkey HPI-Based Estimated Price Increase (%)
2015	2,800	7%	6%	5%
2016	3,200	9%	7%	6%
2017	3,800	11%	8%	7%
2018	4,500	13%	8%	8%
2019	5,200	16%	9%	9%
2020	6,000	18%	8%	10%
2021	7,200	21%	7%	12%
2022	9,000	23%	9%	13%
2023	11,000	22%	8%	14%
2024	14,200	24%	10%	15%

Based on the data for the 2020–2024 period, the net migration to Yomra district increased from 3,200 to 9,100 individuals. This demographic growth has been accompanied by a parallel rise in both construction permits and real estate transactions. The number of building permits issued rose from 721 in 2020 to 1,712 in 2023, marking an approximate increase of 137% (TÜİK, 2024; Yomra Belediyesi, 2024).During the same period, the number of housing transactions climbed from 1,154 to 2,981, indicating a strong wave of supply and demand driven by migration in the local housing market. These developments suggest that the incoming migrant population is largely oriented toward permanent settlement, with a dominant preference for direct property ownership rather than temporary rental arrangements. Supporting this trend, the number of newly registered taxpayers also increased from 319 to 892 in the same period, pointing to a strengthened integration of migrants into the formal economic system (Özüekren & Erder, 2010; Kaya & Kentel, 2005).

In light of these dynamics, it is evident that the housing market in Yomra has been shaped not only by local internal factors but also by external demographic pressures. Particularly after 2022, the accelerated demand for housing has compelled local administrations to expedite the permit issuance process. However, this rapid expansion has not always aligned with spatial planning principles. A qualitative assessment of the increase in construction permits reveals that a significant portion of the new developments consists of housing projects targeting middle- and upper-income groups. This trend has intensified the spatial visibility of urban segregation, further deepening housing disparities between the local population and incoming migrants on a socio-economic basis (Bayırbağ, 2010). Simultaneously, the revitalization of the real estate market has accelerated the rate of property ownership transfers, reinforcing the speculative nature of the market. The fact that housing prices and rental values have multiplied compared to pre-migration periods has exposed low-income groups to an increasing risk of displacement. The newly developed housing areas on the urban periphery, often disconnected from core infrastructure and social services, pose significant challenges to social integration processes (Kaya & Kentel, 2005). On the other hand, the permanence facilitated by property ownership demonstrates that migrant populations are not only economically but also socially and spatially inclined to anchor themselves in the city. The relationship between housing and real estate dynamics and migration in Yomra constitutes one of the most visible dimensions of multidimensional spatial transformation. This construction process, triggered by population mobility, necessitates the revision of local housing policies and the central incorporation of social housing and accessibility principles into post-migration planning frameworks. Otherwise, the pressure of migration on housing risks not only initiating a physical transformation but also deepening spatial inequalities.

The market mobility triggered by migration has had a direct impact not only on housing prices but also on rental values. Particularly since 2020, these increases have placed considerable pressure on local residents' access to housing, reinforcing tendencies toward urban segregation. It is noteworthy that the migrant-origin population predominantly tends to acquire property, whereas the local population remains largely within the tenant segment. This indicates an emerging socio-economic stratification based on property ownership. Data on housing ownership reflected in tax records further support these patterns. According to regional real estate tax declarations obtained from the Trabzon Tax Office Directorate, the number of declared residential property ownerships in Yomra increased by 52% between 2019 and 2024. A significant portion of this growth comprises first-time taxpayers who are migrant investors (Table 2). During the same period, the average tax value per dwelling also nearly doubled. In this context, the real estate activity generated after migration has not only disrupted the supply-demand balance but has also transformed the value structure of urban space, the profile of its users, and the property regime itself. Investment flows shifting from central urban zones to peripheral districts have redefined Trabzon’s spatial development trajectory, creating new imbalances between the city center and emerging growth corridors. In this regard, Yomra should be analyzed not only as a new residential zone but also as the spatial manifestation of migration-induced capital accumulation. This increase, especially in the second-hand housing market, reflects both the rapid transfer of ownership and the growing tendency of migrant populations to establish permanent residence. Indeed, according to the 2023 Annual Report of the Trabzon Tax Office, there has been a 48% rise in the number of new taxpayers over the past five years, with the majority of this increase originating from the Yomra district. Taken together, these findings underscore that Yomra’s real estate market operates not only through supply and demand mechanisms but also in direct interaction with population movements. This highlights the role of migration in redefining spatial organization through economic instruments and points to the deepening risk of ownership-based divisions between local residents and newly arrived populations.

4.1. Comparative analysis of survey and cognitive mapping data

Migration is not merely a physical relocation; it is also a transformative process that reshapes individuals’ spatial perceptions, navigational behaviors, and sense of social belonging. In this study, the shift in settlement tendencies from the Trabzon city center toward Yomra district was analyzed through the method of *cognitive mapping*. This technique was used to visualize how participants perceive their environments, define meaningful places, and prioritize elements within their mental maps (Downs & Stea, 1973; Montello, 2002). The mental maps drawn by participants were evaluated in reference to two distinct periods: the pre-migration phase (centered around Trabzon) and the post-migration phase (after settling in Yomra). The findings reveal a significant transformation referred to as *perceptual center shift*. Iconic locations such as Atatürk Square, Meydan Park, and Forum Shopping Mall—previously central in participants' mental representations of Trabzon—were largely replaced by new residential areas, housing developments, the coastal strip, and local social spaces in Yomra following migration. This observation supports Lynch’s (1960) theory of the “urban image,” emphasizing that individuals’ cognitive maps are continuously reshaped through spatial experiences.

Another striking finding in the mental maps is the weakening of associations with symbolic structures. Iconic sites embedded in the collective memory of Trabzon’s city center—such as the Governor’s Office, Ortahisar Mosque, and Uzun Street—are increasingly underrepresented. In contrast, spatial elements that play a more prominent role in individuals’ daily lives in Yomra—such as residential complexes, parks, and marketplaces—have become more salient. This shift reflects not only a change in the physical use of space, but also a reorientation of individuals’ sense of spatial belonging toward their new residential environments (Tuan, 1977; Canter, 1977). Furthermore, a significant transformation has been observed in participants’ wayfinding behaviors. Before migration, intersections, public buildings, and historical landmarks in the city center served as key spatial anchors for orientation. Following migration, this function has shifted toward large-scale residential compounds, main roads, and shopping centers (Table 4). This change reveals a reconfiguration of individuals’ visual and symbolic connections with the city and signals the emergence of new spatial norms.

These findings demonstrate that migration reshapes not only the physical environment but also individuals’ urban experiences, sense of belonging, and wayfinding practices. Accordingly, the cognitive mapping method served not merely as a spatial tool but as a powerful socio-psychological instrument for understanding the transformation of urban experience in the post-migration context. The survey conducted as part of the study aimed to measure themes such as changing housing preferences, feelings of attachment, accessibility to the city center, spaces of social interaction, and urban imagery following migration. Administered online with a total of 156 participants, the survey captured spatial experiences both prior to and after migration through scoring mechanisms and open-ended responses. When evaluated alongside the findings from the cognitive maps, these data enabled a more holistic understanding of how spatial perception is shaped by both physical realities and cultural/social contexts (Table 5).

Table 4. Cognitive map analysis data

Observation Dimension	Pre-Migration Period	Post-Migration Period
Perceptual Center	Trabzon City Center (Meydan, Uzun Street)	Yomra Coastal Area and New Residential Zones
Symbolic Structures	Historical buildings, public institutions	Shopping malls, residential complexes
Wayfinding References	Mosques, parks, public squares	Road connections, bus stops
Social Focal Points	Areas surrounding Meydan, public spaces	In-site communal areas, marketplaces
Spatial Familiarity and Belonging	Ortahisar, Meydan	Kaşüstü, Şana, Yalıncak neighborhoods

Table 5. Comparison of survey results and cognitive mapping observations

Evaluation Criterion	Survey Findings	Cognitive Map Observations	Interpretation and Methodological Consistency
Definition of Perceptual Center	68% now define “the city center” as Yomra	Drawings focus on Yomra’s coastal area and Kaşüstü	High consistency – clear shift in perceptual center
Representation of Symbolic Structures	72% describe central Trabzon landmarks as “important but distant”	Low representation of Ortahisar, Meydan, etc. on the maps	Consistent – weakening of symbolic associations
Sense of Belonging and Familiarity	61% report “not yet feeling a sense of belonging” in new housing area	Frequent representations of anonymous structures in new neighborhoods	Partial consistency – spatial belonging not yet developed
Wayfinding References	70% refer to bus stops and shopping malls as orientation points	Directional arrows often linked to malls and major roads	Full consistency – shift in wayfinding behavior
Spaces of Social Interaction	59% “more opportunities for social interaction exist in the old city center”	Social focal points densely represented in the older urban core	Consistent – social dominance of the historic center is evident
Access to Public Services	66% report “inadequate access to transportation and healthcare in Yomra”	Public buildings either missing or abstractly depicted on the maps	Consistent – functional disconnect visually represented as well

This comparative analysis offers a significant finding from the perspective of data triangulation. The perceptual changes quantitatively identified through the survey data are qualitatively reinforced by the results of the cognitive map analysis. Key themes such as the shift in perceptual center, changes in wayfinding references, and the repositioning of social interaction spaces show strong alignment across both methodological approaches. This convergence also echoes the theoretical frameworks of Lynch’s (1960) urban imageability and Tuan’s (1977) place attachment. While participants have physically relocated to the new environment, the findings suggest that this new setting has not yet been fully internalized or imbued with meaning in their mental maps. In other words, the cognitive assimilation of space lags behind its physical occupation.

5. Conclusion and recommendations

This study demonstrates that migration is a multifaceted process that transforms not only the physical spaces of cities but also the cognitive, perceptual, and experiential relationships individuals establish with the urban environment. The analyses conducted in the case of Yomra district in Trabzon reveal that the spatial transformation occurring after migration is not limited to population growth and increased housing demand; it also involves significant shifts in individuals’ perceptions of the city, navigational behaviors, and levels of social attachment. The combined evaluation of survey data and cognitive mapping findings confirms the presence of a *perceptual center shift* triggered by migration. Participants’ residential preferences and everyday practices, shifting from the Trabzon city center to Yomra, indicate a functional and symbolic relocation of the urban core. When considered in light of Kevin Lynch’s (1960) theory of the urban image and Yi-Fu Tuan’s (1977) conceptual distinction between “space” and “place,” the findings support the conclusion that individuals’ emotional and cognitive bonds to place are reconfigured through migration. Real estate market analyses further illustrate a substantial increase in indicators such as building permits, property transactions, and ownership transfers in parallel with migratory movements. In particular, the rise in housing sales between 2020 and 2024 suggests that migrants tend toward permanent rather than temporary settlement, thereby directly influencing the spatial and social fabric of Yomra. Moreover, the increase in the number of registered taxpayers reflects the formal integration of this permanence into the economic system.

In order to reconstruct urban memory weakened or lost through migration, it is deemed essential to support investments in public spaces, cultural activities, and shared living environments. Such investments may foster emotional connections between migrants and their new surroundings, contributing to the development of social cohesion and the continuity of spatial belonging. These recommendations highlight that migration should be addressed not only in terms of spatial expansion but also through its perceptual, social, and governance dimensions. The findings from Yomra clearly demonstrate that migration cannot be explained solely by spatial dispersal; rather, it exerts profound effects on individuals' perceptual, social, and symbolic relationships with the city. In this respect, the study offers an original contribution to the relatively underexplored literature on the nexus between migration and spatial perception, providing both theoretical and practical insights for policymakers, urban planners, and local governments. In rapidly growing settlements shaped by migration, urban development should not be driven exclusively by demand, but should be guided by principles of environmental sustainability and social cohesion. The spatial and sociological transformations induced by migration necessitate a multidimensional planning approach. Accordingly, urban expansion tendencies in peripheral districts like Yomra must be supported through integrated migration strategies to prevent unregulated growth. From the perspective of transportation and accessibility, the survey findings and perceptual gaps identified in the cognitive maps indicate the need to redesign urban transport infrastructure to ensure spatial continuity. Strengthening the connectivity between newly developed areas and central urban axes is crucial to reducing time–space accessibility inequalities. The increasing socio-economic divergence between migrant and local populations also leads to ownership-based segregation. To counter this, housing policies that prioritize the production of affordable housing must be developed. Mixed-use and socially interactive residential areas should be promoted as spatial frameworks that enhance social cohesion and foster inclusive urban environments. To effectively implement all of these strategies, it is essential for local governments to adopt dynamic planning tools that integrate land registry, tax, and population data. In particular, the use of participatory analytical methods such as cognitive mapping should be recognized as a valuable instrument for incorporating societal perspectives into planning processes.

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