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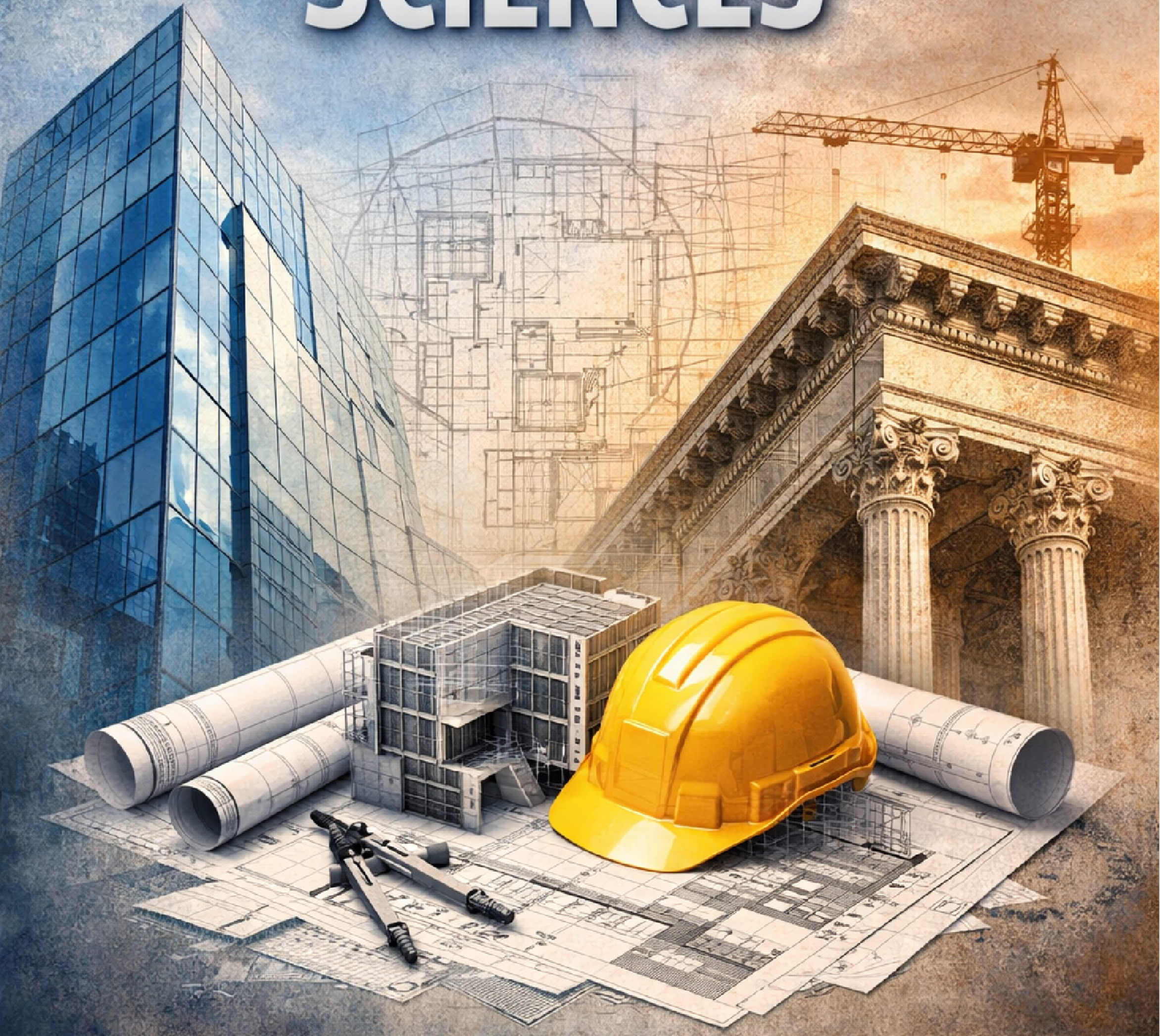

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CONTENTS

CONTENTS

CHAPTER 1

BAY WINDOWS IN HARPUT HOUSES: FORM, FUNCTION, AND MEANING

ZEYNEP SUDE ÇİÇEK[1]
AYŞEGÜL DURUKAN [2]

Introduction

Space is a multifaceted concept that arises when it becomes a tangible environment through the convergence of individual perspectives and society's cultural heritage (Çınar, Yirmibeşoğlu, & Erdoğan, 2024). This definition is notably exemplified in traditional residential architecture: the conventional Turkish house, as a living environment that transcends mere shelter, embodies a comprehensive reflection of spatial cognition, cultural identity, environmental harmony, beliefs, and social interactions.

Yet the systematic documentation and conceptual analysis of the local variations of this architectural heritage still constitute a critical research gap, particularly within the fragile urban fabrics of Anatolia. At this point, the concept should be regarded as a thought

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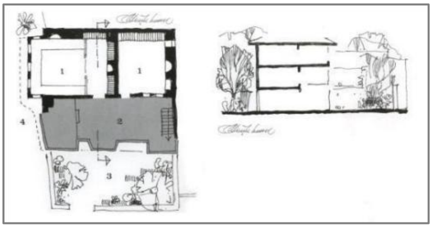
to be understood before moving on to design; it should be considered a fundamental mental framework that encompasses form and gives meaning to spatial existence (Durukan, 2016). The tent used by Turkish tribes during their nomadic period, with its portable structure, circular interior, and functional yet straightforward arrangement, has established the fundamental principles of the Turkish house. With the transition to settled life, these principles transformed into perpendicular architectural plans in Anatolia; as S. H. Eldem (1984) emphasized, the tent's characteristic as an independent living unit crystallized in the concept of the 'room,' which was preserved until the Ottoman period. However, the traditional Turkish house, while maintaining its general architectural features, exhibits significant regional differences influenced by local materials, climate, and topography. This differentiation has laid the groundwork for the development of unique typologies across various regions of Anatolia; however, comparative analysis of these typologies and systematic evaluation of local adaptation mechanisms have remained limited in the literature. This study aims to address the aforementioned gap specifically in the context of the Harput settlement. Harput is one of the rare examples where a unique 'Harput House' typology has developed, skillfully blending stone and wood, due to its historical accumulation and challenging topography. The bay window element, a distinctive feature of Harput houses, notably exemplifies a multifunctional architectural solution tailored to the region's sloped terrain, severe climate conditions, street fabric, and privacy-focused social interactions. Nevertheless, the formal attributes of the Harput bay window, including its structural logic, contribution to the street fabric, and its integration within the broader Turkish house typology, remain insufficiently examined. In this context, the central question of the study is: How have the porch implementations in Harput houses interacted with local environmental conditions and socio-cultural dynamics to create a unique typological diversity? This study follows three sub-objectives to answer this question:

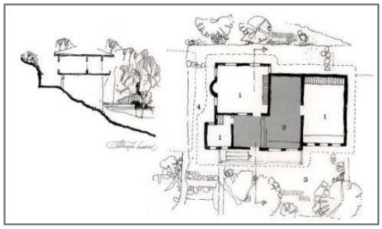
- To conceptually define the general structural features of the Turkish house and the position of the bay window within this system,
- To systematize the definition, typology, and functional diversity of the cumba through the literature,
- To evaluate the impact of the city's geographical and parcel fabric on architecture in Harput, through fieldwork and typological analysis, focusing on the morphological and structural features of porch types and their contribution to the street fabric.

The importance of the study can be evaluated on three levels. At the theoretical level, it adds a systematic analysis of local adaptation mechanisms to the traditional literature on the Turkish house. At the methodological level, it proposes an analytical framework that comprehensively addresses the multi-layered functionality of the porch element (climatic adaptation, spatial expansion, street-residence interaction, privacy provision). If it is practical, it aims to create a typological reference for the preservation and restoration of Harput's fragile historical fabric.

The nomadic life, which is the previous way of life in Turkish culture, is the most important stage that laid the foundations of spatial organization. Central Asian tent architecture shows structural similarities to the plan scheme of the Turkish house, characterized by a focus on the center, a closed orientation to the outside, and an inward-looking spatial concept. This similarity is not only formal but also evident in spatial hierarchy and usage practices. The circular arrangement organized around the central fire pit in the tent has evolved into the concept of a sofa in settled life; independent living units have transformed into room typologies. The common architectural discourse that emerged during the Seljuk period accelerated the adaptation of this order to settled life; the residential arrangement, which centers on the concept of the room and is shaped around the sofa, became institutionalized during this period. During the Ottoman period, the Turkish house typology matured and acquired its characteristic features: elements such as a wooden skeleton system, protrusions and bay windows, the separation of the haremlik and selamlık, built-in closet and door details became standardized (Yıldırım & Hidayetoğlu, 2009). The traditional Turkish house, which has persisted for centuries by adapting to the climate, topography, and concepts of privacy, has been replaced by modern housing typologies due to changing needs and lifestyles of the 20th century (Özel, 2019). It should not be forgotten that, over time, traditional Turkish houses have shown significant diversity across the cultural, climatic, and sociological contexts in which they spread and were adopted. In all examples, it is observed that design decisions serve a specific purpose: many building elements and details, such as floor usage and sofa typologies, are reflected in the space as elements of living culture. This integrity transforms the Turkish house from merely a form of residence into a living space that intertwines culture, social structure, climate, and topography. The bay window element is one of the most distinctive and multifunctional components of this holistic system. The spatial organization of the traditional Turkish house is based on the hierarchical relationship between the core rooms and the sofa, which connects them and serves as a shared living space. The room, which serves a multifunctional purpose, accommodates most of the individual's daily activities; the sofa serves as the social backbone connecting these independent living units. As S. H. Eldem (1954) noted, the integration of these two elements led to the emergence of the characteristic design system of the Turkish house. The concept of the oda (room) originated in the nomadic period's tent life, where each family had an independent living unit. With the transition to settled life, this independence principle was preserved, but spaces were reconnected through the sofa. Regardless of the materials used, rooms, sofas, and similar structural components have carried not only functional but also cultural meanings. Details based on accessibility and usability (built-in wardrobes, step arrangements, storage units, and shelves) have given the space a strong identity (Küçükerman, 1985). All of these elements embody the inward-looking and multifunctional concept of the Turkish house.

Figure 1. Section and plan of a traditional Turkish house built within a sloped landscape, showing the relationships between rooms and the sofa. (a-Safranbolu, b-Bursa)

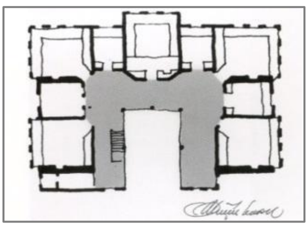


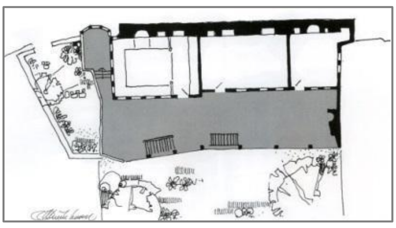


a b

Reference: (Küçükerman, 1985)

Figure 2. a - Section and plan of a traditional Turkish house built in a hot climate, showing the relationships between rooms and the sofa. Adana; b - Section and plan of a traditional Turkish house built in a cold climate, showing the relationships between rooms and the sofa. Kütahya





a b

Reference: (Küçükerman, 1985)

Hybrid Load-Bearing System: Material and Technical Integration

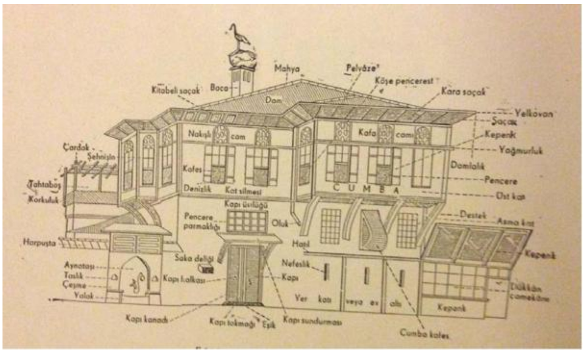
The load-bearing system of the Turkish house is based on a mixed structural arrangement that combines different materials and construction techniques. This integrated system has maintained its continuity for centuries as a harmonious synthesis of geographical conditions and local material sources. While the solid stone walls on the ground floor provide a sturdy foundation for the structure, a lightweight wooden skeleton with mud brick infill rises on the upper floors. The structural logic of this hybrid approach is straightforward: stone walls provide moisture protection and structural stability, while the wooden frame offers flexibility and lightness.

Wooden beams placed on stone walls regulate load transfer and ensure the structural integrity of the upper floors (Kuban, 1995). The flexibility provided by the timber structural system enabled the construction of bay windows, one of the most distinctive features of the Turkish house. In this way, regular and functional room layouts could be achieved on the upper floors, even on irregular plots (Eldem, 1954). This system is not only a structural necessity but also a rational design strategy for space acquisition and the rationalization of plan organization.

An inward-oriented lifestyle culture, principles of privacy, and the multi-layered historical heritage of Anatolia have shaped the façade arrangement. In early Anatolian houses, the fusion of Islamic traditions and Byzantine legacy made family privacy the fundamental determinant of the design. Although the relationship with the street is confined to a few windows, the primary openings of the residence are typically the interior spaces that access the garden or courtyard via semi-open galleries, which serve as the common hall, known as the sofa (hayat) (Kuban, 1995). This arrangement spatially encodes a lifestyle model that is closed off to the outside but open to the interior. Thus, the façade design not only creates an aesthetic exterior surface but also reflects the functional structure of the interior space and the street's natural reflection of the structural system. The contrast between the blind ground-floor rooms prioritizing privacy and the upper-floor rooms opening to views and daylight has shaped the characteristic façade rhythm of the traditional Turkish house. This rhythm, repeated throughout the street fabric, has also contributed to the formation of urban identity.

In this context, the bay window is one of the most distinctive and multifunctional elements of Turkish residential architecture. These enclosed projections, formed by the outward extension of rooms or sitting areas above the ground floor, create a three-faceted space that extends toward the street (Turani, 1980). Unlike the generic bay window concept in Western architectural traditions, which primarily emphasizes spatial enlargement and daylight admission, the cumba and the şahnişin in Turkish house architecture embody a more complex interplay of privacy, social observation, and façade articulation. These projecting elements function not only as spatial extensions but also as mediators between the domestic interior and the public realm of the street (Cerasi, 2001) Smaller and more compact projecting spaces are designated as bay seat (şahnişin), and their perimeter is articulated with windows, facilitating the observation of street activity. The main difference between a bay window and a bay seat is in spatial scale and functional density: a bay window covers an entire room or a significant part of it, while a bay seat is a seating area integrated into a window arrangement within a more limited space. Bay windows that emerged due to the narrow parcels in the old city fabric, constrained by walls, have both expanded living space on the upper floors and provided a controlled connection to the outside world through an inward-focused plan. Bay windows are classified into two main categories based on their spatial location: room bay windows and sofa bay windows. In terms of material composition and load-bearing system, they are further categorized into three principal types: simple cantilevered projections, tiered cantilevered projections, and braced projections. Braced bay windows are the most commonly used type in traditional Turkish houses, as the load is transferred to the main wall through supporting braces (Çetin, 2006). This typological diversity demonstrates the existence of flexible adaptation strategies based on structural capacity, parcel conditions, and spatial needs.

Figure 3. Illustration showing the concepts of bay window and bay seat in C. E. Arseven's Sanat Ansiklopedisi.



Reference: (Arseven, 1950)

Figure 4. The Bay Window in the Shared Room at Sakarya Alicanlar House

Reference: (Çetin, 2006)

Bay windows are not merely visual façade elements but multidimensional design components that perform spatial, environmental, social, and economic functions. From a functional perspective, they provide benefits such as clarifying spatial organization on irregular plots, expanding rooms, and increasing access to natural daylight. At the environmental level, bay windows create an eave effect that protects the lower walls from rain and solar radiation, thereby forming a climatic buffer zone. At the social level, within the inward-oriented plan of the Turkish house, the bay window is one of the most significant components of the dialogue between interior and exterior spaces. By carrying the rhythm of the street fabric, everyday flow, and outdoor dynamism into the interior, it strengthens the relationship that household members establish with their surroundings (Şenyurt, 2016). Economically, the bay window is a rational solution that maximizes usable area while minimizing land loss on narrow parcels. This multi-layered functionality explains why bay windows have become so common in traditional Turkish houses. However, the formal and structural features of the bay window vary significantly depending on local climate, topography, parcel layout, and social dynamics. In this context, it is necessary to examine how the bay windows typologies in Harput houses have developed a typological diversity within the region's unique geographical and cultural conditions.

Harput Houses

Harput, which forms the foundation of Elazığ's cultural, historical, and architectural infrastructure, can be described as the center where the modern city's characteristic identity is shaped (Çelik, 2019). The historic city of Harput is located in the Upper Euphrates region of Eastern Anatolia, approximately 5 km north of Elazığ's city center, and today it is a neighborhood of Elazığ. The Harput Plateau, on which the settlement is located, has an average elevation of 1,450-1,500 meters and features a high topography, distinguished from the surrounding plains by a noticeable elevation difference of 300-500 meters (Tonbul, 1985). This elevation difference has provided three critical advantages in the city's historical development. First, it has created a natural defense; Harput Castle has strengthened its strategic position. Secondly, Uluova, Elazığ Plain, and Kuzova have provided economic control opportunities by establishing visual and geographical dominance over fertile agricultural areas. Thirdly, thanks to its location along regional trade routes, Harput has become an important commercial crossroads. The detection of cultural traces dating back to the Urartu period in the region indicates that Harput has served as a strategic settlement center since at least the 1st millennium BC (Erzen, 1984).

The street fabric and parcel layout of Harput have been shaped primarily by the region's challenging geography and historical defense needs. The limited flat area, the settlement confined by city walls, and the sloped topography have contributed to the development of an organic street pattern and irregular parcel geometries. Buildings constructed under these conditions are mostly arranged in a contiguous order; on suitable parcels, detached houses with gardens have been built (Öztürk & Coşkun, 2014). However, in shaping the urban fabric, religious experiences, economic conditions, and social relations have also been decisive beyond geographical constraints. The formation of neighborhood units clustered around religious structures such as mosques, medreses, and tombs; the organization of commercial axes around marketplaces and caravanserais; and the prioritization of neighborly relations' privacy have shaped the morphological character of the street fabric. Especially in sloped terrain, the gradual placement of residences has brought about a strategy of expanding both the view and the air rights over the street through bay windows on the upper floors.

Figure 5. General View of the Traditional Harput Street

Reference: (Öztürk & Coşkun, 2014)

The architectural character of Harput houses maintains the fundamental principles of traditional Turkish house typology while also embodying a synthesis influenced by the region's unique geographical and climatic conditions. At the core of this synthesis is the goal of achieving the highest structural and environmental performance from the natural properties of the materials used. The load-bearing system of the structures has a complex configuration in which the compression resistance of the load, the thermal insulation provided by the brick, and the flexibility of the wood form a complementary whole (Özdemir, Uzun, & Spor, 2014). When examining the examples that have reached us today, it is observed that Harput houses follow a characteristic structural stratigraphy:

- The ground floor of the Bodrum structure features masonry stone walls that constitute its foundation. The region's abundant basalt and limestone supply both moisture insulation and structural robustness. Typically, stone walls are left unplastered to preserve the material's natural appearance.

- Upper floors are constructed by supporting adobe blocks with wooden beams. The wooden beams placed between the adobe blocks aim to withstand horizontal stresses and enhance structural durability under earthquake forces. This system optimizes load distribution by strategically positioning lightweight adobe components atop substantial stone structures.

- Roof coverings are constructed using adobe and compacted earth, which serve as thermal mass in response to the region's severe continental climate conditions. Preference is given to timber and traditional Turkish roof tiles for roofing applications.
- Bay Windows and Projections: The use of timber and the hımış technique in the construction of bay windows on façades provides both lightness and structural flexibility (Olğun, 2022). Bay windows completed with adobe infill on a timber frame and finished with external wooden cladding constitute a rational solution in terms of material economy and climatic comfort.

Figure 6. Example of the Connection of Stone Wall and Wooden Beams: Şefik Gül Cultural House West Façade

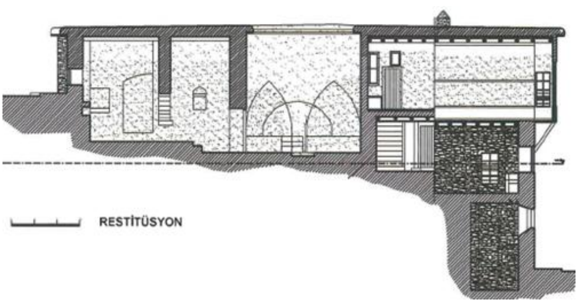
Reference: (Öztürk & Coşkun, 2014)

This hybrid construction system facilitated the construction of Harput houses in stepped configurations on inclined terrains, while also permitting the secure implementation of projections. In particular, supporting bay windows with timber brackets and braces ensures structural stability while providing additional spatial gain on the upper floors. The stone-brick-wood hybrid structure also exhibits flexible structural behavior in response to the earthquake risk in the region. This architectural synthesis is the fundamental factor that distinguishes Harput houses within the traditional Turkish house typology. The region's harsh climate conditions (hot summers, cold winters, high temperature differences between day and night), sloped topography, and limited flat areas have made the bay window not only an aesthetic façade element but also a spatial, structural, and climatic necessity.

Figure 7. The Façade with bay window in Traditional Harput Houses

Reference: (Öztürk & Coşkun, 2014)

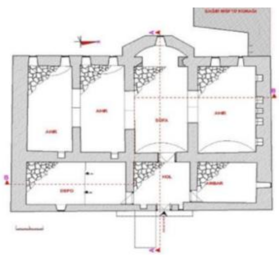
Figure 8. Wooden bay seat and Bracket Elements in Section A–A of the Sağır Müftü Mansion Restitution Project



Reference: (Öztürk & Coşkun, 2014)

The interior layout of traditional Harput houses parallels the fundamental features of Turkish residential architecture. The ground floors are designated for production, storage, and livestock activities; the upper floors are organized as residential units where daily life takes place. Turkish house plan types are classified as inner courtyard with a living room, outer courtyard with a living room, without a living room, and with a central courtyard (Durukan & Türk, 2023). The standard interior courtyard plan type in Anatolia has also been preferred in Harput houses (Öztürk, 2014). The basis for this choice lies in the requirements to provide climatic comfort, protect privacy, and adapt to irregular parcel geometries.

Figure 9. Ground Floor Plan of the Küçük Efendi Mansion Illustrating the Spatial Relationship Between the Inner Sofa, the Rooms, and the Stables



Reference: (Öztürk, 2009)

Figure 10. Section A–A of the Küçük Efendi Mansion Illustrating the Vertical Spatial Organization and the Relationship Between the Ground Floor, Upper Floor, and Living Spaces

Reference: (Öztürk, 2009)

In Harput, the bay window is the fundamental architectural element that provides spatial expansion on the upper floors and determines the façade's movement. These projections, placed on the stone walls on the ground floor, brought the building closer to the street, increasing the interior's lighting and spaciousness. Bay windows, particularly the subtype known as bay seats and traditionally referred to as “şahnişin” or “köşk,” are predominantly located within sofa spaces; in certain buildings, however, they are positioned within the selamlık (formal reception) section. From a formal perspective, rectangular-plan bay windows are prevalent in the Harput examples; however, polygonal forms were also constructed. The pentagonal projection on the western façade of the Küçük Efendi Mansion represents a characteristic example of this typological diversity (Öztürk, 2024). Regarding window arrangement, bay seats on the façades were predominantly designed with five or seven windows (Öztürk, 2009). This intensive use of openness has determined the fill-vacancy ratio on the façades, creating the characteristic rhythm of Harput streets. The projection of sequential bay windows into the street has created significant environmental effects in narrow streets. By providing shade, it protects against excessive summer sunlight, while in winter it acts as a buffer against snow and wind. This situation shows that the balcony functions not only as a spatial gain but also as a passive climatic design strategy.

Sociocultural Functionality: Privacy, Observation, and Social Relations

The spatial organization of Harput houses reflects the family structure, privacy principles, and social relationships in Turkish-Islamic culture. The presence of rooms without windows on the street façade alongside the bay windows extending to the street reflects the cultural balance between privacy and observation. This dual strategy maintains the traditional Turkish house's inward-looking character while upholding the principle of controlled interaction with the outside world. Bay windows have a privileged position in social life because they allow you to see guests coming in advance and to have control over street life (Olğun, 2022). In the regions of Elazığ and Harput, kürsübaşı is a longstanding indigenous tradition characterized by communal musical gatherings held in residential spaces and village rooms, where social interaction and collective cultural expression are prominently observed (Koçak, 2003). As a practice emphasizing unity, conversation, and shared rituals, kürsübaşı assumes a fundamental role in organizing familial life and social relationships within the domestic environment. Within this cultural context, bay windows attain a distinguished status in Harput houses, owing to their ample daylight and expansive visual perspective, positioning them as natural congregating areas for family members and as the spatial counterpart to the kürsübaşı tradition (Aydın & Ünüvar, 2020). This functionality reveals that the bay seat does not merely serve a spatial role, but actively materializes social hierarchy within the domestic interior.

The bay windows located opposite each other on the narrow and sloped streets of Harput at the urban scale have served as a visual communication tool in neighborhood relations. The approach of the opposing bay windows created a semi-private area on the street, both limiting privacy and strengthening social interaction. The dual character of the bay windows (both open and closed) is one of the main factors shaping Harput's unique urban fabric.

Current Situation and Conservation Issue

The settlement that began on the Harput Plateau shifted to the Elazığ Plateau in the 20th century; with this migration, new construction in Harput has come to a halt. The traditional fabric has been significantly damaged; only nine houses and nineteen registered buildings have survived to the present day (Coşkun, 2009). This limited number underscores the need for systematic documentation of Harput’s distinctive bay window typology. The modernization process has weakened the principles that shape the spatial identity of Harput houses. Merely imitating traditional forms in a formal sense has led to the loss of original spatial logic and cultural meaning. Traditional bay windows, which emphasize privacy and provide light and structural flexibility, have been reconfigured into outward-facing reinforced concrete balconies. This transformation denotes both a conceptual and structural rupture. Therefore, Harput's original architectural identity cannot be preserved solely through restoration interventions limited to individual structures. Protection approaches developed within a holistic urban context are essential. The new structures should not be superficial imitations of traditional forms; instead, they must be considered in line with cultural factors, spatial logic, and structural originality (Olğun, 2022). In this context, cumba should be understood and preserved not only as a historical façade element but also as a carrier of Harput's social, cultural, and environmental identity.

When examining the unique adaptation of traditional Turkish residential architecture in Harput through the jumba element, it is concluded that spatial formations are not merely technical solutions; rather, culture, geography, and social life dynamics intertwine to shape the architecture. The research findings confirm the main argument of the study on three levels: the first being the typological level, where Harput's bay window preserves the general Turkish house bay window tradition while showing regional variation. The central space concept, inherited from Central Asian tent tradition, combined with Harput's sloped topography and harsh climate, has evolved into a unique housing culture compatible with local material knowledge (stone, adobe, wood hybrid) and construction techniques (Timber-framed infill construction, post-and-beam construction).

The presence of rectangular and polygonal bay windows together, the prevalence of bay windows with five to seven windows, and the placement strategies along the sofa-room axis are concrete indicators of this local adaptation. Secondly, it has been observed that bay windows provide multi-layered performance at the functional level, such as spatial expansion, natural lighting, climatic comfort (shade and wind buffering), and visual dominance over the street. This also highlights that the bay window should be considered as a passive design strategy due to its multifunctionality. In terms of parcel allocation and the rationalization of irregular geometries, bay windows have been a rational solution arising from structural necessity. Third and finally, it is concluded that bay windows spatialize the balance between privacy principles in Turkish-Islamic culture and the observation of the outside world at the socio-cultural level. These areas, where the family gathers, guests are hosted, and the 'Kürsübaşı' tradition is embodied, have enriched domestic life while also supporting the aesthetic continuity of the street fabric. The fact that the mutual bay windows serve as a visual communication tool in neighborly relations proves that the bay window extends beyond its structural boundary and is part of a larger urban-scale unity. However, the research findings also reveal that this unique architectural identity is under serious threat. The modernization process, the shift of the city center to Elazığ, and the dominance of reinforced concrete technology in construction have made Harput's traditional residential fabric vulnerable. The fact that only a few registered structures have survived to the present day illustrates the extent of this fragility. Bay windows, originally designed with lightweight materials and privacy principles, have transformed into reinforced concrete balconies that lack both functional and cultural significance; this change has weakened not only the architectural typology but also the social realm of meaning. This situation demonstrates that preserving the traditional housing culture in Harput cannot be limited to restoration interventions at the individual building scale. A holistic approach to conservation and use is essential. As stated in the 2018 Harput Report (Yalın, 2018), "A place must be lived in to remain alive"; accordingly, the sustainability of Harput depends on re-envisioning traditional houses not as static heritage objects but as functional spaces adapted to contemporary ways of living.

In conclusion, the Harput bay window constitutes more than a mere historical architectural element; it embodies a multifaceted response shaped by geographical, cultural, and social influences. The typological, functional, and socio-cultural insights derived from this research demonstrate that the bay window underscores Harput's residential identity. Implementing a comprehensive conservation strategy that appreciates both the cultural and spatial importance of bay windows ensures the preservation of Harput's housing heritage, maintaining its physical integrity and preserving its significance. Such an approach extends beyond basic preservation, providing an invaluable opportunity to learn from local adaptation techniques pertinent to contemporary Anatolian residential architecture.

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CHAPTER 2

THE TRANSFORMATION OF ARCHITECTURAL VISUALIZATION PROCESSES WITH GENERATIVE AI: AN EXPERIMENTAL APPROACH

MUSTAFA HAKİ ERASLAN[1]

Introduction

The discipline of architecture has undergone a parallel evolution with technological advancements, transitioning from basic drawing instruments to sophisticated computer-aided design (CAD) systems over centuries (El Moussaoui, 2025; 1). Significant breakthroughs in design processes have occurred since the integration of computer technologies into architectural practice, starting in the 1960s (Sancak, 2023; 47). Particularly in recent years, with the maturation of artificial intelligence (AI) and machine learning techniques, generative design approaches previously limited to experimental domains have begun to integrate into mainstream architectural practice (Akdağ & Künyeli, 2025; 675). This transformation has been highlighted by the emergence of probabilistic methods, such as neural networks (Zeytin et al., 2024;

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3), and has accelerated with the development of systems like Generative Adversarial Networks (GANs) (Goodfellow et al., 2014; 3) and diffusion models (Zeytin et al., 2024; 3). Generative AI fundamentally reshapes architectural design through its capacity to create diverse content, including text, visuals, music, and 3D models (Li et al., 2024; 760). Specifically, since early 2022, the widespread adoption of large visual models like DALL-E 2, Midjourney, and Stable Diffusion has propelled the use of AI in architecture into a "deployment phase" (Maslej et al., 2023; 3; Li et al., 2024; 760).

The role of AI in the architectural discipline is multifaceted, offering the potential to enhance both creativity and efficiency. AI is integrated into various stages of the architectural design process, ranging from conceptual phases to construction detailing (El Moussaoui, 2025; 1). In this digital transformation, technologies such as Computer-Aided Design (CAD), Building Information Modeling (BIM), 3D modeling, Virtual Reality (VR), and Augmented Reality (AR) are increasingly being incorporated into architectural education (Söylemez et al., 2025; 398; Özeren et al., 2024; 167). In the realm of planning and layout generation, tools like Maket can analyze project constraints, such as plot size and room relationships, to produce thousands of early-stage design options within minutes (El Moussaoui, 2025; 9). Generative design algorithms assist architects by exploring numerous design variations based on predefined criteria. In the field of energy analysis and sustainability, AI models support performance-based designs; for instance, tools like Digital Blue Foam rapidly conduct wind and solar analyses, providing critical information for environmental impact and sustainability assessment (El Moussaoui, 2025; 9). AI systems have been observed to achieve a 40% reduction in energy consumption in data centers (El Moussaoui, 2025; 11). For form-finding and 3D form design, AI enables the exploration and refinement of building volumes and fundamental spatial configurations (Li et al., 2024; 768). Tools that transform text-to-3D models, such as DreamFusion (Poole et al., 2023; 4) and Magic3D (Lin et al., 2023; 304), facilitate the rapid creation of architectural 3D models (Li et al., 2024; 767).

One of the most notable areas in architectural practice where these developments manifest is in architectural visualization (rendering) processes. Traditional rendering engines (V-Ray, Lumion, etc.) generally require complex geometric models and are time-consuming. However, AI-supported image processing techniques, particularly Image-to-Image and Text-to-Image approaches, have revolutionized this process. Architects can now produce visually compelling and hyper-realistic visuals from text descriptions (prompts) or quickly obtain visual results using AI-supported image processing based on inputs like screenshots of 3D mass models or hand-drawn sketches. This capability offers designers the opportunity to rapidly create visual depictions of spatial ideas without the necessity of complex geometric modeling (El Moussaoui, 2025; 2). The rapid visualization of ideas and hypotheses is vital in the iterative nature of architectural design, as the speed of AI in the visualization phase far exceeds human capability. The instantaneous transformation of keywords or sketches into visual representations helps designers quickly examine and experience their concepts, thus shortening design cycles and reducing project delivery times (Li et al., 2025; 2; Akdağ & Künyeli, 2025; 676). This speed and flexibility enable designers' decisions to be data-driven, rational, and focused on creative solutions (Kurtuluş, 2025; 122).

The purpose of this study is to reveal the role of AI in the process of generating renders from a prepared 3D model, utilizing accessible and established AI visual generators: Rerender AI, Archivinci, and MyArchitect AI. The usability of these AI-supported models compared to traditional rendering engines and their role in architectural design are evaluated. In this context, a villa structure modeled in SketchUp was used to obtain rendered images from three different generative AI applications, and the outputs were comparatively analyzed. The study compares the data obtained from different AI platforms using identical prompts.

Material and Method

This study relies on a comparative analysis model examining the performance and interpretative differences of various artificial intelligence infrastructures (algorithms) used in architectural visualization processes when applied to the same input data. The research methodology is structured in three stages: "Preparation of the Base Model," "Selection of Tools," and the "Controlled Experiment Process."

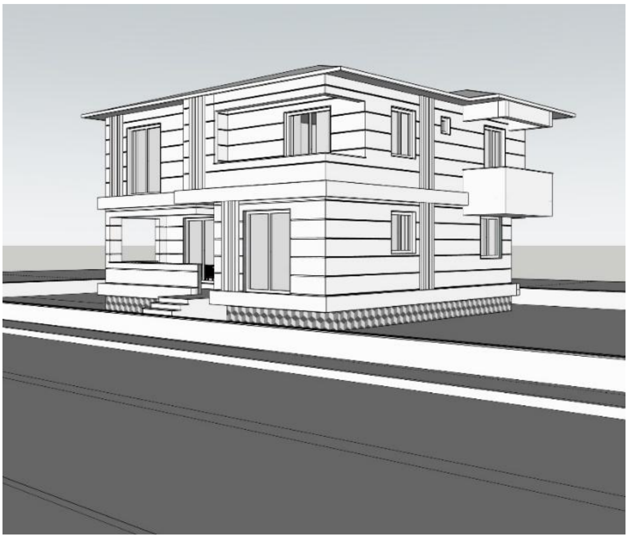
Preparation of the 3D Base Model

Trimble SketchUp, one of the most widely used software in architectural design offices, particularly during concept and preliminary design phases, was chosen to create the experimental basis of the study (Figure 1). The primary factors for selecting SketchUp include the ability to rapidly produce massing studies, its intuitive interface allowing designers to quickly transfer ideas into the third dimension, and its capability to cleanly export the clear edges required by AI tools.

The designed model represents a detached villa typology with a two-story, modern architectural style. In the mass composition, the perception of depth is enhanced through cantilevered overhangs created on the upper floor, recessed terrace areas, and vertical decorative elements on the facade. To define the structure's relationship with the ground and to test the AI's ability to distinguish between the "built environment" and the "natural environment," the model was not limited to the building alone. A defined driveway at the front facade and a planar garden area (landscape base) surrounding the structure were included in the modeling using simple geometric forms (Figure 1).

As preparation for the rendering phase, the model was exported as a “raw” (clay mode) structure, completely stripped of texture, color, and shadow details, defining only the volumetric form, solid-void ratios, and environmental boundaries (road-garden). This approach was adopted to observe whether AI tools could correctly assign different textures, such as asphalt, grass, and facade materials, to the appropriate surfaces using only form and perspective information, without being influenced by color data.

Figure 1 View of the Raw Model.



Selection of Artificial Intelligence Tools

In this study, three different web-based AI platforms were identified, standing out for their accessibility in architectural design offices and visualization processes. These tools were selected as Rerender AI, Archivinci, and MyArchitectAI.

All selected platforms utilize “Image-to-Image” technology and operate on a browser-based principle. The selection of these tools was influenced by their capacity to understand architectural terminology (Natural Language Processing), user-friendly interfaces, and specialized algorithms for converting raw sketches into photorealistic visuals.

Application Method: Standardized Prompt Test

A standardized single text command (Master Prompt) was used to objectively measure the tools' capabilities in "semantic interpretation" (understanding the text) and "geometric fidelity" (adhering to the model).

During the experiment, the following prompt was entered into the Rerender AI, Archivinci, and MyArchitectAI platforms without any modifications:

"A contemporary 2-story modern villa architecture. Facade materials include white concrete, large floor-to-ceiling glass windows, and natural wood cladding accents. Located in a lush landscaped garden. Bright sunny daytime, clear blue sky, warm natural light. Architectural photography style, photorealistic, highly detailed textures"

In all three tools, the "Image Strength/Influence" parameter was kept constant at an optimum level (ranging between 0.6 - 0.8) to preserve the geometry of the model while allowing for texture assignment. Thus, the aim was to compare the three different results produced with the same mass and the same prompt in terms of material quality, light-shadow consistency, and architectural aesthetics.

Findings

In this section, the visual results obtained by processing the raw (clay) model generated in the Trimble SketchUp environment (Figure 1) using standardized text prompts on the MyArchitectAI

(Figure 4), Rerender AI (Figure 2), and Archivinci (Figure 3) platforms are analyzed comparatively.

The analyses were conducted based on three main parameters: “Geometric Fidelity,” “Material Interpretation,” and “Environmental Context/Atmosphere.”

Figure 2 ReRender AI image

Figure 3 Archivinci image

Figure 4 MyArchitect AI image

Geometric Fidelity and Form Perception

The raw model used as input data, seen in Figure 1, features a modern mass configuration with two stories, cantilevered overhangs, and a pitched roof.

- Rerender AI (Figure 2): It produced one of the results most faithful to the geometric boundaries of the structure. It clearly defined window mullions and balcony railings, presenting a sharp architectural expression by preserving the linear edges of the raw model.
- Archivinci (Figure 3): While successfully maintaining mass proportions, it emphasized verticality on the facade. It processed the wooden finishes around the windows in a way that added depth to the model's geometry.
- MyArchitectAI (Figure 4): It handled the geometry with a softer language. Although it preserved the main contours of the building, it blurred the boundaries by blending the structure with vegetation, especially at the junction points with the ground.

Material and Texture Interpretation

The commands "White concrete facade" and "Natural wood cladding" specified in the Master Prompt were interpreted differently by each artificial intelligence tool:

- Rerender AI: It presented material transitions with high contrast. It processed wood claddings as horizontal panels and also used initiative by detailing the structure's plinth level (base) with stone cladding, although not specifically mentioned in the prompt.
- Archivinci: It handled the wood texture in a warmer and more saturated tone. The plaster texture on the white facades

is perceptible. Reflections on glass surfaces were adjusted with a transparency that slightly reveals the interior space.

- MyArchitectAI: It exhibited a more artistic approach in the material palette. Wooden elements were presented in a brighter and reddish tone under the effect of sunlight. Glass surfaces were depicted with a strong mirror effect reflecting the surrounding landscape.

Atmosphere and Environmental Context (Hallucinative Interpretation)

The most distinct difference among the AI tools emerged in their "context generation" capabilities. The phrase "Lush landscaped garden" in the prompt transformed into three different scenarios:

- Urban/Street Interpretation (Rerender & Archivinci): Both Rerender AI (Figure 2) and Archivinci (Figure 3) preferred to position the structure along a roadside. The pavement and asphalt textures added to the foreground shifted the structure to a more "urban" scale. This indicates a tendency of the AI to fill voids with a logical urban texture (pavement, road).

- Pastoral/Villa Interpretation (MyArchitectAI): MyArchitectAI (Figure 4), unlike the others, constructed a more dramatic atmosphere. Although not specifically requested in the prompt, it exhibited the behavior of filling voids with creative objects, termed "AI Hallucination," by adding an ornamental pool/water feature to the foreground. "Golden Hour" was chosen as the lighting condition, adding a warmer and more inviting atmosphere to the visual.

Conclusion

In this study, the process of transforming a raw mass model generated in the Trimble SketchUp environment into photorealistic visuals using web-based generative artificial intelligence tools—specifically Rerender AI, Archivinci, and MyArchitectAI—was experimentally examined. The obtained findings indicate that a fundamental paradigm shift is occurring within the architectural visualization discipline and that artificial intelligence technologies have become an undeniable reality of architectural production practice.

Comparative analyses demonstrated that “Image-to-Image” technologies eliminate the constraints of “time and technical expertise,” which constitute the most significant barriers in traditional rendering processes. Processes such as material assignment, lighting adjustment, and rendering, which could take hours or even days using traditional methods (e.g., V-Ray, Corona), have been reduced to the order of seconds thanks to AI-supported platforms. The ability of all three platforms used in the study to impart distinct and high-quality atmospheres to the same raw model within seconds concretizes the speed and efficiency advantages this technology offers to design offices.

The most critical outcome of the study is the fact that artificial intelligence is transforming the role of the architect. The architectural designer is evolving from a “technical practitioner” who processes every single pixel, into a “curator” or “director” who guides the AI tool with precise commands (prompts), selects the optimal results, and manages the overall process. As observed in the MyArchitectAI example, the AI’s ability to autonomously fill voids (e.g., landscape, water features) offers inspiring new perspectives to the architect during the early stages of design.

In conclusion, AI-supported visualization tools are of critical importance not only for the presentation of the final product (final render) but also for generating rapid variations during the design maturation process and supporting decision-making mechanisms. It is evident that in the architectural practice of the future, designers capable of collaborating with AI and possessing “Prompt Engineering” competence will stand out in professional competition. This study demonstrates that artificial intelligence is not a threat supplanting the architect; rather, it is an indispensable “design assistant” that unlocks creative potential and alleviates technical burdens.

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CHAPTER 3

EMBEDDED SPATIAL INTELLIGENCE IN TRADITIONAL HOUSING

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Introduction

Traditional housing across different geographies is not merely a collection of building types, but a layered and relational spatial system shaped through ongoing interactions between people, environment, and technique. This layered condition calls for an approach that moves beyond defining traditional housing as a purely formal entity. Such an approach considers housing together with the processes of everyday life, care, and transformation through which it is inhabited and maintained.

Much of the existing literature on traditional housing architecture, has predominantly focused on descriptive categories such as formal typologies, local material use, and climatic

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adaptation. In Turkish housing studies, classifications based on plan types, sofa configurations, and façade organization have provided a strong framework for identifying and comparing typological characteristics (Eldem, 1955; Aksoy, 1963). While this framework has been central to defining traditional housing, it has also enabled alternative readings that focus on how these structures are lived in, maintained, and transformed over time. Understanding traditional housing as a living and open-ended spatial system offers a complementary perspective to the predominantly descriptive tendencies of the literature.

Within this framework, this study foregrounds the concept of embedded spatial intelligence, understanding domestic space as a field of knowledge produced through practices of making, using, and caring. Embedded spatial intelligence does not conceptualize space merely as a designed formation; it frames space as a relational practice shaped through continuous interactions between material, body, and environment. Tim Ingold's definition of spatial knowledge as an experiential process acquired through making and dwelling, instead of an abstract design outcome, provides an important theoretical reference for this approach (Ingold, 2013). From this perspective, traditional housing is approached not as a fixed heritage object, but as a living practice that attains continuity through processes of care, use, and transformation over time. This also enables an understanding of the body–space relationship through the ways in which space is experienced and continually reproduced.

The study addresses the body–space relationship not as a spatial arrangement that disciplines or governs the body, but as an environment that accompanies bodily experience, guides movement, and establishes conditions for engagement. In the phenomenological tradition of architecture, Pallasmaa's understanding of space as articulated through the senses and the body provides a key point of departure. Complementing this view, the approaches of Holl, Pallasmaa, and Pérez-Gómez, which conceptualize architectural experience as a perceptual and bodily continuity, offer a theoretical basis for analysing why threshold spaces, decisions of scale, and degrees of permeability in traditional housing enable flexible and layered uses rather than producing rigid spatial boundaries (Holl et al., 2006; Pallasmaa, 2012).

Studies that examine the culture–space relationship through environmental determinants or perceptual legibility (Rapoport; Lynch) have established a significant framework for interpreting the cultural dimensions of space. In these approaches, space has largely been conceived as a definable and classifiable spatial construct. Here, space is not treated as a direct expression of cultural codes, but as a lived spatial field continuously shaped through everyday use, bodily routines, and practices of care. Accordingly, comparison is articulated not through formal elements in isolation, but through the ways in which these elements are embedded within patterns of inhabitation, spatial relations, and shared responsibilities that give architectural form its meaning. Spatial ethics is approached through the ways in which space organizes everyday life, enables forms of cohabitation, and shapes the degrees of freedom of movement. Rather than being framed as a system of abstract moral principles or normative values, ethics is understood here as the quality of the relationships that space establishes with people, the environment, and the community. In this sense, traditional housing is approached not as an idealized model, but as a set of instructive references through which the long-term implications of spatial decisions, along with relations of care and continuity, can be critically examined. This perspective resonates with care ethics, which understands ethics through everyday practices and relationships, and enables spatial decisions to be evaluated in terms of the relations they sustain, the practices they support, and the vulnerabilities they respond to. This ethical perspective extends beyond a human-centred framework to include a material ethics that attends to the relationships between material, body, and environment. The selection of local materials, their repairability, and their capacity for transformation over time are thus understood not merely as technical or economic choices, but as integral to the relational and ethical ties that space establishes with its surroundings. Considered together, care ethics and material ethics allow spatial ethics to be understood not as an idealized or prescriptive framework, but as a relational practice grounded in sustaining, repairing, and living together.

Since the 1990s, readings of traditional housing through environmental sensitivity and ethical values have occupied a significant place within the literature on vernacular architecture and sustainability. Much of this work has approached sustainability primarily through technical parameters such as energy efficiency, material use, and climatic adaptation. By contrast, the ways in which space is engaged in everyday life, together with practices of care and its relationships to social life, have often remained secondary. Rather than reiterating these established approaches, the present study seeks to rethink traditional housing in relation to contemporary concerns, including climatic uncertainty, the increasing invisibility of care practices, and ongoing debates on spatial justice.

The United Nations Sustainable Development Goals (SDGs) are employed as a shared analytical framework through which spatial decisions can be examined in terms of care, continuity, and collective responsibility (United Nations, 2015). The SDGs are not treated as numerical performance indicators or normative assessment tools, but as a conceptual language that situates architectural practice within contemporary social and ecological debates.

SDG 11 foregrounds questions of inclusivity and spatial justice through housing and practices of living together, while SDG 12 renders visible historical practices of repairability, local production, and material circularity. SDG 13, reframes climate not as a problem of technical optimization, but as a condition that invites architecture to be reconsidered through capacities for uncertainty, adaptation, and negotiation. In this sense, the SDGs do not classify traditional housing as "compliant" or "exemplary," but provide a relational lens through which spatial decisions, the relations they sustain, and the vulnerabilities they adress can be critically understood.

The study first outlines the conceptual framework of embedded spatial intelligence and its methodological approach. It then undertakes a comparative analysis of selected traditional housing examples located in different regions of Türkiye—namely Rize, Tarsus, Akçaabat, and Şile–Akçakese—examined through the lenses of ecological sensitivity, technical–craft relations, and the body–space–ethics nexus. The findings are subsequently discussed in relation to the SDGs, forming the basis for a critical reflection on how the relational and ethical dimensions of traditional housing knowledge can inform and extend contemporary architectural practice.

Methodology

The selected case studies—Rize, Akçaabat, Tarsus, and Şile–Akçakese—were chosen as representative contexts of traditional housing developed under distinct climatic, material, and socio-cultural conditions within Turkey. Rather than aiming for exhaustive coverage or typological completeness, these cases provide a comparative ground for examining how ecological sensitivity, technical knowledge, and body–space relations are articulated across different regional settings of vernacular housing.

This study adopts a qualitative and interpretive research methodology. The primary data consists of texts, drawings, and spatial observations derived from the authors' previous fieldwork conducted in the settlements of Rize, Tarsus, Akçaabat, and Şile–Akçakese (Süyük Makaklı, E., & Atalan, Ö.,2012, 2013, 2016, 2019). This existing empirical material was systematically re-examined in line with the study's theoretical framework.

Rather than approaching traditional housing through formal typologies or historical classifications, the analytical process focused on interpreting housing environments through their relational conditions. These include interactions with local ecological contexts, everyday practices of use, cycles of care and repair, and embodied spatial experience. The re-reading of the material aimed to reveal how spatial decisions are produced and sustained through these interrelated practices. The analysis combined physical components—such as plan configurations, construction techniques, and spatial organization—with social and experiential data, including seasonal patterns of use, threshold spaces, traces of use, and locally embedded practices. This combined reading enabled an interpretation of how spatial decisions acquire meaning within a network of materials, practices, and environmental conditions. The comparative approach was structured not around formal similarities between cases from different geographical contexts, but around the socio-cultural practices, relations of care, and environmental negotiations through which spatial decisions become meaningful.

The United Nations Sustainable Development Goals (SDGs) were employed as an analytical framework rather than as normative evaluation criteria. In particular, SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) were used to frame a critical discussion of care, responsibility, and long-term continuity in spatial production, allowing ethical, social, and environmental dimensions to be considered simultaneously.

Figure 1. Schematic representation of the study's methodological process

Embedded Spatial Intelligence and Ecological Sensitivity:

A Relational Logic between Climate, Space, and Everyday Life

In traditional housing, ecological sensitivity develops not through the technical optimization of climatic data, but through a relational structure in which climate, material, the body, and everyday practices are interwoven. Environmental conditions therefore operate not simply as background parameters shaping spatial decisions, but as constitutive elements working alongside material knowledge, construction techniques, and social rituals. Ecological sensitivity thus gains meaning not through isolated architectural elements, but through the continuity and interactions these elements establish with everyday life.

To grasp this relational network, architectural elements—such as eaves, courtyards, thick walls, or the sofa—need to be approached not merely as direct responses to climate, but as points of intersection where multilayered spatial and social practices converge. In the traditional housing of Rize and Akçaabat in the Black Sea region, wide eaves and elevated floors are not simply solutions devised for protection from rainfall. Field observations indicate that these elements also embody an embedded material knowledge concerning the behaviour of timber under humid conditions, while supporting a culture of care that opens the space beneath the eaves to practices of storage, production, and neighbourhood interaction.

This spatial arrangement demonstrates how principles of resource circularity and responsible production—discussed in contemporary sustainability discourse under SDG 12—are integrated into everyday spatial arrangements rather than articulated as abstract objectives.

Similarly, in the traditional housing of Tarsus, shaped by the Mediterranean climate, thick stone walls and inward-oriented courtyard layouts cannot be read solely as passive cooling strategies. This spatial configuration produces a relational spatial ethic formed through the interaction between the thermal mass of stone, local hearth traditions, and the balance between privacy and shared family life. The courtyard thus functions not only as a climatic buffer, but as a spatial arrangement through which ideas of safe, inclusive, and shared space—adressed under SDG 11—are reproduced at the scale of the dwelling through everyday practices.

In the Şile–Akçakese settlement, sofas and projecting elements likewise extend beyond their role as technical devices that mediate prevailing wind directions. They emerge instead as semi-open threshold spaces where seasonal transitions are experienced bodily and where production and social interaction intersect. Field observations indicate that these spaces support multiple uses, including vegetable drying, everyday sitting, and the provision of gradual permeability toward the street. This condition points to the presence of spatial arrangements that operate in cooperation with climate, rather than as closed systems designed to resist it.

This reading departs from approaches that frame ecological sensitivity primarily through a set of "green solutions" or technical performance indicators. In traditional housing, sustainability does not appear as a fixed outcome, but as a relational process continuously reproduced through interactions between material, the body, and everyday practices. In this sense, the Sustainable Development Goals function not as criteria for validating traditional housing, but as an analytical lens through which the historical formation of these micro-scale spatial relationships can be examined.

Such relational ecological sensitivity should not be understood as a spontaneous form of environmental adaptation, but in connection with the local technical knowledge, material literacy, and craft practices that make it possible. The negotiation established with climate is therefore not the result of an abstract design decision, but of a form of technical intelligence learned through making and dwelling. For this reason, the following section turns to an examination of the nature–technique–craft relationship that underpins ecological sensitivity.

Nature – Technique – Craft: Knowledge Learned through Making and Dwellin

In traditional housing architecture, technical knowledge emerges not as an abstract engineering calculation or a standardized mode of production, but as a form of knowledge shaped through lived experience with nature, material, the body, and time. From this perspective, the relational network between climate, space, and everyday life discussed in the previous section can be understood not only as a spatial arrangement, but also as an expression of a technical intelligence acquired through making and dwelling. Here, *technique* gains meaning not as a neutral tool limited to the definition of construction systems, but as a domain of production in which relationships between environmental conditions, local resources, and human labour are articulated spatially.

As observed through fieldwork, construction techniques employed in traditional housing across different geographies were intended to establish systems that are accessible, repairable, and reproducible. The timber frame systems, wattle and daub, and infill techniques seen in the houses of Rize and Akçaabat reflect an embedded knowledge of wood's behavior in humid climatic conditions. In these structures, load-bearing elements were not treated as permanent and unchangeable components, but as parts that could be disassembled, repaired, and renewed as needed. The construction process thus functioned not as a completed act, but as an open-ended technical system sustained through ongoing practices of maintenance and repair.

This approach generates a technical ethic that allows buildings to age and understands material not merely as a consumable resource, but as a material condition that changes over time and requires ongoing care and maintenance. Such an ethic involves attentiveness to material properties, the reading of traces of ageing and use as carriers of knowledge, and the sustained relationship established through repair. Maintenance, in this sense, emerges as a constitutive practice that enables the transmission of technical knowledge across generations.

In Tarsus, where the Mediterranean climate is a defining factor, stone masonry and hybrid construction systems aim not only to ensure structural durability, but also to establish a balance between the thermal properties of material and everyday life. Thick stone walls contribute to thermal regulation while also supporting a material ethic oriented toward long-term use. Fieldwork observations indicate that stone walls are maintained, extended, or reconfigured over time, generating a building culture oriented toward continuity rather than a singular moment of “completion.” This condition reveals technical knowledge not as an expertise confined to the craftsperson alone, but as a collective field of knowledge that evolves through interaction with users.

In the Şile–Akçakese settlement, timber frame and infill systems reveal a mode of production that is low-tech yet highly dependent on craftsmanship. Materials are locally sourced, and construction processes are largely carried out on site and grounded in experiential knowledge. The dimensions of building components, joint details, and surface treatments are determined through the craftsperson's direct engagement with material. Craft thus emerges not merely as a technical skill, but as a mode of learning based on reading the behaviour of material, allowing room for error, and accepting the traces that accumulate over time.

This mode of production demonstrates that knowledge transmitted through master–apprentice relations and local labour is not limited to a technical transfer alone. It also fosters social solidarity, shared knowledge, and economic continuity. In this respect, traditional housing production generates a spatial articulation of concerns discussed under SDG 8—particularly decent work and local economic resilience—within contemporary sustainability debates. Similarly, repairable and reproducible construction systems reveal how the objectives of SDG 12, often addressed today under the framework of the circular economy, have historically taken form through everyday practices at local scales.

Traditional housing should therefore be understood not as the outcome of technological deficiency, but as the product of a situational rationality shaped by the constraints of resources, time, and labour. This rationality does not conceive sustainability as a field of optimized performance metric; instead, it frames it as a practice learned through making and dwelling and continually reproduced over time. The nature–technique–craft relationship thus offers not a model to be replicated, but a critical reference that reminds contemporary architecture of modes of care, responsibility, and long-term thinking. In this sense, craft is not merely a technical skill associated with the act of building, but an experiential relationship through which the body engages with material, space, and time. As will be discussed in the following section, this bodily dimension of technical knowledge directly shapes how space is experienced and how it operates as an ethical interface.

Body – Space – Ethics: The Spatial Politics of Everyday Life

In traditional housing architecture, space is conceived not as an instrument that directs or disciplines the body, but as an interface attentive to bodily movement, everyday rhythms, and social relations. Scale, spatial transitions, and threshold areas do not fix the individual's position within space; rather, they offer a configuration open to multiple modes of use and temporal variation. This condition indicates that space operates not merely as a physical arrangement, but as an ethical field of relations that quietly shapes how everyday life is lived.

The ecological sensitivity and embedded technical intelligence discussed in the previous sections are, in this sense, inseparable from bodily experience. Negotiations with climate, technical knowledge developed through engagement with material, and practices of care acquire meaning directly through the body's movements and habits within space. In traditional housing, the body does not appear as a passive user of space, but as an active agent that continually redefines spatial conditions.

As observed through fieldwork, the permeability established between enclosed, semi-open, and open spaces in traditional housing across different geographies produces graduated transitions rather than confining the body within rigid boundaries. Threshold spaces such as the sofa, courtyard, balcony, and hayat negotiate a balance between privacy and shared presence. These spaces do not operate as corridors that direct bodily movement or as zones of control; instead, they function as flexible environments that enable everyday encounters, moments of pause, and practices of production.

In the Şile–Kabakoz settlement, doorless transitions opening onto the sofa and balcony offer clear examples of this bodily permeability. Field observations indicate that these spaces are actively used not only for circulation, but also for vegetable drying, everyday sitting, neighbourhood interaction, and children's play. In this context, the sofa functions not as a fixed boundary between interior and exterior, but as an intermediate space that allows the body to engage with space at different rhythms and across different times.

Similarly, in traditional housing in Tarsus, spatial organization structured around the courtyard offers a configuration that remains open to changing patterns of use throughout the day, rather than directing bodily movement along a single axis. The courtyard accommodates diverse practices—such as food preparation, resting, children's play, and neighbourhood interaction—within a shared spatial framework. This condition suggests that space operates not as a mechanism of bodily discipline or control, but as a spatial ethic attuned to bodily and social needs.

In the housing of Rize and Akçaabat in the Black Sea region, semi-open spaces likewise establish a balanced relationship between protection and openness without fully severing the body's contact with climate. Areas beneath wide eaves and transitional spaces enable everyday life to maintain engagement with the exterior despite conditions of rainfall and humidity. Field observations reveal that these spaces are used as intensively as enclosed volumes in terms of everyday production, storage, and social interaction.

These examples demonstrate that spatial organization is conceived not as a rigid structure that governs the body, but as a flexible system that operates in coordination with bodily presence. Spatial control is enacted not through direct restrictions or hierarchical arrangements, but indirectly through patterns of use and forms of mutual observation. In this sense, spatial ethics is understood less in terms of discipline and surveillance than as a logic of organization that enables cohabitation.

Within this study, ethics is defined not through abstract moral principles, but through the ways in which space provides a ground for bodily existence and relations of care. Traditional housing offers critical reference points that render visible how spatial decisions quietly shape the social and political texture of everyday life. Threshold spaces, semi-open areas, and permeable arrangements function not only as devices that facilitate movement, but also as spatial settings in which mutual observation, shared responsibility, and practices of care are organized. These spaces allow bodily freedom while simultaneously reproducing social norms and hierarchies through embodied habits.

In this sense, the body–space–ethics relationship shifts sustainability away from being framed as a problem of environmental performance and repositions it within the micro-politics of everyday life. These micro-politics reveal how the ideals of inclusive and accessible space articulated by SDG 11 are materialized through thresholds, permeabilities, and collective patterns of use. The balances negotiated between privacy and co-presence further indicate, in relation to SDG 10, that space can function not only as an interface that reinforces inequalities, but also—under certain everyday conditions—as one that mitigates them.

Within this framework, traditional housing offers a critical grammar through which sustainability can be read not primarily through large-scale planning discourses, but as the spatialization of ethical and care-based relations between bodies. Threshold spaces regulate spatial access not through absolute rules, but through everyday negotiation, allowing differences of age, gender, and use to coexist more flexibly within space. This condition provides an important insight into how spatial inequalities may be softened not solely through large-scale planning decisions, but through practices of everyday use. The findings of the relational reading conducted across the three main analytical axes are summarized below in a series of analytical synthesis tables prepared for each case study. These tables present a comparative overview of spatial decisions observed in the housing of Rize, Tarsus, Akçaabat, and Şile–Akçakese, structured around the shared analytical categories defined in the methodology. The final row of the tables, titled relational ecological sensitivity, makes visible the dialogue established between the findings and the Sustainable Development Goals (SDGs 11, 12, and 13).

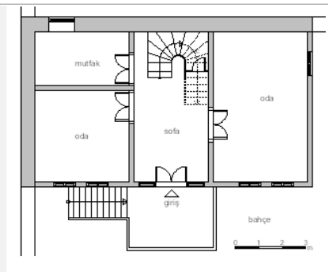
Table1. Embedded Spatial Intelligence in Şile-Akçakese/İstanbul Compact Analytical Synthesis

Conceptual Axis	Embedded Empirical Reading (İstanbul-Şile-Akçakese)	
Embedded Spatial Intelligence	Housing is largely constructed by local craftsmen and users, where spatial knowledge is transmitted through lived experience, bodily memory, and repetition rather than abstract representation. Space thus operates as a situated and experiential field of knowledge.	 (Authors' archive)
Building – Dwelling – Maintenance Continuum	Timber frame, wattle & daub, and hımış systems remain open to repair, disassembly, and renewal, framing the house as an ongoing process sustained through routine care rather than a finished architectural object. This continuity embeds both care ethics and material responsibility.	 (Authors' archive)

<table>
<tr><td>Lived Spatial Practice & Thresholds</td><td>Room–sofa arrangements support multiple everyday activities—living, eating, washing, storage, and seasonal production—while balconies and semi-open spaces extend domestic life outward, mediating climate, labour, and social interaction.</td><td>
(Authors’ archive)</td></tr>
<tr><td>Relational Spatial System</td><td colspan="2">Variations in storey number, plan organization, and spatial hierarchy respond to household size, economic conditions, and incremental change, revealing an adaptive system shaped by use, maintenance, and contextual negotiation rather than fixed typology.


(Authors’ archive)</td></tr>
<tr><td>Body–Space Interaction & Care Ethics</td><td>Stairs, entrances, sofas, and circulation elements function as spaces of pause, encounter, and production. Visible wear, material aging, and repair traces register bodily routines over time, positioning space as lived, written, and continuously renegotiated.</td><td></td></tr>
<tr><td>Relational Ecological Sensitivity (SDG 11–12–13)</td><td colspan="2">Climatic adaptation is achieved through spatial organization, material choice, and everyday use rather than technical optimization. Housing supports co-existence (SDG 11), repair-based production (SDG 12), and long-term climatic adaptability (SDG 13) as intertwined practices.</td></tr>
</table>

Table 2. Embedded Spatial Intelligence in Akçaabat -Trabzon Compact Analytical Synthesis

Conceptual Axis	Embedded Empirical Reading (Trabzon-Akçaabat)	
Embedded Spatial Intelligence	Housing knowledge in Akçaabat is shaped by local building traditions, topography-sensitive placement, and repeated construction practices rather than abstract design rules. Spatial intelligence emerges through adaptation to steep terrain, climate, and collective dwelling habits.	 (Akın, E.S. et al)
Building – Dwelling – Maintenance Continuum	Timber frame systems combined with stone infill and plastered facades form repairable and incrementally adaptable structures. The house functions as an open-ended process sustained through maintenance rather than a fixed architectural product.	 (www.akcaabatpostasi.com)
Lived Spatial Practice & Thresholds	Inner sofas, raised entrance platforms, and garden-mediated access support everyday practices of movement, encounter, and seasonal living. Thresholds operate as spaces where domestic life, climate, and social interaction are gradually negotiated.	 (Akın, E.S. et al)

Relational Spatial System	Variations in plan type (predominantly inner-sofa), storey number, and settlement grouping respond to slope, household structure, and visual relations rather than standardized typologies, producing a flexible and relational spatial order.	 www.akcaabatpostasi.com
Body–Space Interaction & Care Ethics	Stairs, elevated entrances, sofas, and garden walls register bodily routines over time. Visible wear, material aging, and repetitive use patterns embed care, continuity, and everyday responsibility into spatial organization.	 (Akın, E.S. et al
Relational Ecological Sensitivity (SDG 11–12–13)	Climatic adaptation is achieved through orientation, section, material choice, and everyday use rather than technical optimization. Housing supports collective life (SDG 11), repair-based material continuity (SDG 12), and long-term adaptation to climatic variability (SDG 13).	

Table 3. Embedded Spatial Intelligence in Rize: Compact Analytical Synthesis

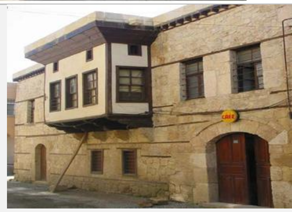
Conceptual Axis	Embedded Empirical Reading (Rize)	
Embedded Spatial Intelligence	Spatial knowledge in traditional Rize houses is shaped through long-term negotiation with steep topography, intense rainfall, and humidity. Building	

	practices rely on local craftsmanship and experiential knowledge, where material choice and construction logic evolve through repeated use rather than abstract design rules.	 (https://www.rize.gov.tr/tas-ve-ahsap-yapilar)
Building – Dwelling – Maintenance Continuum	Hybrid systems combining stone masonry at ground level with timber frame and muskalı dolma infill above create lightweight yet resilient structures. These systems remain open to repair and replacement, ositioning the house as a process sustained through continuous maintenance under harsh climatic conditions.	 (https://www.rize.gov.tr/tas-ve-ahsap-yapilar)
Lived Spatial Practice & Thresholds	Semi-open spaces, raised entrances, and interior sofas support everyday practices shaped by rain, mud, and seasonal movement. Thresholds function as protective buffers where daily life adapts to climate rather than retreating entirely indoors.	 (https://www.rize.gov.tr/tas-ve-ahsap-yapilar)
Relational Spatial System	Plan organization, section, and material layering respond directly to slope, drainage, and ground conditions. The spatial	

	system prioritizes elevation, permeability, and lightness, producing flexible arrangements that adjust to environmental constraints rather than fixed typological ideals.	 (https://www.rize.gov.tr/tas-ve-ahsap-yapilar)
Body–Space Interaction & Care Ethics	Timber stairs, floors, and circulation elements register repetitive bodily movement and moisture-related wear. Visible aging and frequent repair embed care, vigilance, and responsibility into everyday spatial practices.	
Relational Ecological Sensitivity (SDG 11–12–13)	Climatic adaptation is achieved through elevation from ground moisture, breathable wall systems, wide roof overhangs, and material lightness. Housing supports resilient dwelling (SDG 11), repair-based material continuity (SDG 12), and long-term adaptation to extreme rainfall and humidity (SDG 13).	

Table 4. Embedded Spatial Intelligence in Tarsus: Compact Analytical Synthesis

Conceptual Axis	**Embedded Empirical Reading (Mersin-Tarsus)**	
Embedded Spatial Intelligence	Spatial knowledge in Tarsus houses emerges through long-term adaptation to Mediterranean climate, dense urban fabric, and courtyard-based living, where construction practices and spatial organization are shaped by repeated use rather than abstract design rules.	 (Authors' archive)

Building – Dwelling – Maintenance Continuum	Stone masonry ground floors combined with timber frame and adobe upper structures form durable yet repairable systems. Houses remain open to incremental change—extensions, functional additions, and repairs—sustaining continuity through maintenance rather than fixed completion.	
Lived Spatial Practice & Thresholds	Courtyards, entrance halls, and sofas organize everyday life, hosting living, working, storage, and seasonal activities. These spaces mediate privacy, climate, and social interaction, functioning as lived thresholds rather than circulation-only zones.	 (Authors' archive)
Relational Spatial System	Plan organization, storey number, and spatial hierarchy vary according to household needs and urban constraints. Former service spaces (stores, stables, depots) are gradually transformed, revealing a relational system shaped by use and socio-economic change rather than typological fixity.	 (Authors' archive)
Body–Space Interaction & Care Ethics	Stairs, entrances, and upper-floor terraces register repetitive bodily movement, climatic use, and material aging. Visible wear and repair traces embed care, responsibility, and everyday ethics into the spatial fabric.	 (Authors' archive)

Relational Ecological Sensitivity (SDG 11–12–13)	Thick stone walls, inward-oriented courtyards, wide overhanging eaves, and shaded bay windows supported by diagonal cantilever support enable passive cooling and protection from rainfall and solar exposure, positioning climatic adaptation as a spatial and structural negotiation rather than a technical optimization.

Discussion and Conclusion

This study rereads traditional housing architecture through the interconnected lenses of ecological sensitivity, technical knowledge, and body–space relations. It demonstrates that these three axes do not operate independently, but intersect within the same spatial decisions. Findings derived from fieldwork show that spatial configurations negotiating with climate cannot be understood separately from technical choices shaped by local materials and craftsmanship, as well as from everyday bodily practices.

Within this context, embedded spatial intelligence emerges not as a set of isolated solutions or fixed principles, but as a relational network of decisions that gains continuity over time through processes of care, use, and transformation. Across different geographical contexts, recurring spatial logics become visible despite formal and regional variation. These shared logics do not point to a homogenized architectural language, but to a relational mode of spatial thinking in which maintenance, bodily practice, and material negotiation consistently shape the built environment. Here, similarity functions not as an analytical limitation, but as empirical evidence of an embedded spatial intelligence operating beyond stylistic or regional classification.

Recurring Spatial Logics	Spatial Expressions across Case Studies
Maintenance as Spatial Continuity	In all cases, buildings remain open-ended systems sustained through routine repair rather than fixed completion
Space as Lived and Produced Practice	Space is produced through everyday bodily practices rather than predefined functional zoning
Threshold-Based Organisation	Transitional spaces consistently mediate climate, social interaction, and movement
Materiality and Ethical Engagement	Local materials age, transform, and require care, positioning materiality as relational rather than consumptive
Climate as Negotiation	Environmental adaptation operates through spatial organisation rather than technical optimisation

Ecological sensitivity, in this study, is not understood as the optimization of environmental performance. Instead, it is approached as a process of reciprocal adjustment between climate, material, and everyday life. In Rize and Akçaabat, wide eaves are not merely technical responses to rainfall; they embody an embedded knowledge of timber's behaviour in humid conditions and support a culture of care that opens the space beneath the eaves to practices of production, storage, and neighbourhood interaction. Similarly, in Tarsus, thick stone walls and inward-oriented courtyard layouts reflect a spatial balance between the thermal behaviour of material, privacy, cohabitation, and daily rhythms, extending beyond passive cooling strategies. In the Şile–Kabakoz settlement, sofas and projecting elements emerge as threshold spaces where technical adaptation to wind conditions intersects with bodily experience of seasonal change and gradually structured social interaction. Together, these examples indicate that ecological sensitivity gains meaning not through individual architectural elements, but through the relationships these elements establish with everyday practices.

Evaluations of technical knowledge and craftsmanship further reveal that what is considered "technical" in traditional housing is largely learned through lived experience. Fieldwork observations show that timber frame systems, stone masonry walls, and hybrid construction techniques are treated not as closed or finalized systems, but as structures open to repair, addition, and transformation. This approach produces a technical ethic in which material is understood not as a consumable resource, but as a partner that ages, bears traces of use, and requires care. Rather than being fixed at the moment of design, technical knowledge evolves collectively through ongoing practices of use and maintenance.

From the perspective of body–space relations, traditional housing does not configure space as a rigid apparatus that disciplines the body. Instead, space operates as an interface attentive to bodily movement, everyday rhythms, and social relations. Spatial traces observed during fieldwork make this relationship materially legible. In residential courtyards, traces of use along floor surfaces between the well and the kitchen reveal how the repeated bodily practice of carrying water produces a stable movement route over time, shaping space through use. Similarly, the concentrated wear along the central axis of wooden stair treads demonstrates that vertical circulation functions not as an abstract circulation diagram, but as a movement regime produced through repetitive bodily practice, weight transfer, and temporal continuity. Such traces make visible that space is not only designed, but continuously rewritten through bodily presence.

Within this context, spatial ethics is defined not through abstract normative principles, but through the ways space organizes everyday life, enables certain relationships, and responds to specific vulnerabilities. The care ethics perspective adopted in this study approaches ethics through everyday practices and relations of responsibility, while material ethics emphasizes that the selection, use, and transformation of materials constitute an ethical field in themselves. Within this framework, care ethics provides the ethical grounding through which maintenance is understood not as a technical afterthought, but as a constitutive spatial practice. In traditional housing, spatial decisions generate subtle yet effective micro-politics that make room for both caring and cared-for bodies. Threshold spaces, semi-open areas, and permeable layouts establish ongoing negotiations between privacy and co-presence, offering important insights into how spatial justice can be produced at the scale of everyday life.

The Sustainable Development Goals are employed in this study not as performance benchmarks, but as an analytical framework that enables the ethical, social, and ecological dimensions of spatial production to be discussed in contemporary terms. SDG 11 foregrounds issues of inclusivity and accessibility through housing and threshold spaces, while SDG 12 renders visible practices of repairability, local production, and material circularity as historically embedded spatial practices. SDG 13 reframes climate not as a problem of technical optimization, but as a condition that invites architecture to be reconsidered through its capacity for adaptation and negotiation. This rereading suggests that sustainability in architectural practice should be evaluated not only through performance metrics, but through everyday use, care, and transformation.

In this sense, traditional housing is approached not as a model to be directly replicated, but as a set of relational examples that demonstrate how space, environment, and social relations can be jointly configured. These examples do not propose the reproduction of specific solutions, but represent historical manifestations of a mindset that places relational thinking, care-oriented practice, and contextual negotiation at the centre of design. The critical task for contemporary architectural practice, therefore, is not to imitate the past, but to rethink the spatial intelligence observed in traditional housing in relation to present-day vulnerabilities and uncertainties. Traditional housing reflects not a pursuit of maximum comfort or universal models, but a form of situated rationality developed to make everyday life possible under the constraints of its historical moment. The value of these examples lies not in their direct applicability today, but in the spatial reasoning through which they negotiated necessity, resource limitation, and environmental pressure.

In conclusion, this study approaches traditional housing architecture not as an idealized heritage of the past, but as a critical ground for reflecting on the ethical dimension of architecture through relations of care, responsibility, and material engagement. Embedded spatial intelligence articulates architecture's contribution to human well-being not through abstract ideals, but through everyday practices, bodily experience, and sustained relationships with material. The challenge, therefore, is not to replicate historical forms, but to reinvent this relational and ethically grounded mode of thinking as a contemporary architectural language capable of responding to today's spatial crises.

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CHAPTER 4

CULTURAL ROUTES AS A TOOL FOR HERITAGE GOVERNANCE: THE COUNCIL OF EUROPE PROGRAMME[1]

EMRE KARATAŞ[2]

Introduction

Throughout history, numerous routes have existed worldwide serving purposes such as trade, communication, transportation, and pilgrimage. Along these routes, accommodation facilities and commercial structures were constructed to meet the needs of travelers, merchants, and pilgrims. Moreover, civilizations have been shaped around these routes (Karataş, 2025, p. 49).

In the early stages of the development of cultural tourism, the concept of a "route" was understood as a physical transportation

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[1] a) This study is derived from the doctoral dissertation titled "An Integrated Methodology Proposal for the Design of Cultural Routes: The Revitalization of Historical Travelers' Itineraries Passing Through Safranbolu," prepared by Dr. Emre Karataş under the supervision of Prof. Dr. Aysun Özköse at Karabük University, The Institute of Graduate Programs, Department of Architecture. b) ChatGPT-5.2 and Gemini 3 were used for English language editing and paraphrasing (https://chatgpt.com/, accessed on 20 December 2025; https://gemini.google.com, accessed on 20 December 2025).

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corridor connecting destinations. Over time, it evolved into a network-based notion encompassing both tangible and intangible connections (ICOMOS, 2008; Pedrosa, Martins, & Breda, 2022). Within this framework, the concept of the "route" is evaluated as a boundary object. Boundary objects are tangible and intangible constructs that facilitate the connection between various factors possessing the potential for mutual interaction (Del Chiappa, Bregoli, & Kim, 2019).

A UNESCO report (1994) concerning cultural heritage routes underscores that the concept embodies a global vision, amalgamating tangible and intangible components alongside material and spiritual values. In this context, cultural routes, which evolve dynamically through the contributions of diverse components, possess multifaceted dimensions that transcend their apparent functions (UNWTO, 2015).

Cultural routes are utilized as instruments for sustainable site management and cultural heritage governance, aiming to highlight the shared elements of societies and foster cooperation, dialogue, and development (Iakovaki, Konstantakis, Teneketzis, & Konstantakis, 2023).

These routes may encompass monuments, archaeological remains, historical sites, and architectural and natural assets, as well as intangible or invisible elements such as vanished values. In this regard, the ICOMOS Charter (2008) underscores that cultural routes necessitate an interdisciplinary approach due to the diversity of cultural heritage and the complexities inherent in its management.

In the late 1980s, international organizations such as UNESCO, ICOMOS, UNWTO, and the Council of Europe (COE) undertook initiatives aimed at strengthening the tourism dimension of cultural routes. In this context, The Cultural Routes of the Council of Europe programme, which was launched by the COE in 1987 with a single route, encompasses 49 routes as of 2025. Within the scope of this programme, the COE certifies cultural routes for various objectives (Council of Europe, 2025a).

In this study, 49 Cultural Routes certified by the COE by the end of 2025 were categorized in the context of their number of countries, spatial categories, thematic source, key theme, design structure, main purpose, and certification years. Multiple Correspondence Analysis (MCA) was applied to the categorized data of these examples using the IBM SPSS Statistics 27 software. Through this analysis, the relationships between categorical variables were analyzed multidimensionally. By positioning the route examples and categories on a two-dimensional plot based on similar combinations of characteristics, common profiles, distinct clusters, and outliers were identified.

The study aims to serve as a guide for new examples to be planned and registered by demonstrating the change and development of the theoretical approach to the concept of cultural routes within the COE certification process.

Cultural Routes from a Tourism Perspective

The negative impacts of mass tourism, such as environmental degradation, the deepening of social inequalities, and the decline of cultural diversity, have become more evident over time (Akis, 2011). Nevertheless, the accumulation of knowledge and the expansion of communication opportunities have heightened the level of interest in cultural heritage, leading to an increase in the number of individuals gravitating toward this field.

The World Tourism Organization defines cultural tourism as a type of tourism activity in which the visitor's essential motivation is to learn, discover, experience and consume the tangible and intangible cultural attractions/products. The primary elements of cultural tourism are identified as a society's art, architecture, history, tangible cultural heritage, culinary culture, literature, music, crafts, and intellectual, spiritual, and emotional characteristics. It is further emphasized that the main purpose of cultural tourism is to promote and protect the cultural elements that make destinations attractive to visitors by preserving and promoting cultural assets such as living cultures, lifestyles, value systems, beliefs, and traditions (UN Tourism, 2025).

The concept of "route tourism" is widely embraced by both academic circles and industry stakeholders for the purpose of holistically organizing various approaches, such as cultural, natural, and rural tourism, within extensive areas possessing comprehensive and multidimensional values (UNWTO and ETC, 2017). Cultural routes, from a tourism perspective, are generally perceived as a tool that supports tourism (UNWTO, 2015).

The strategy of cultural routes lies in establishing networks between multiple heritage resources. By assessing heritage values holistically, it aims to create a tourism product that is more potent than the sum of its individual components. For instance, a modest archaeological site or a small rural place of worship may not possess sufficient attraction on its own. However, when these elements are integrated through a cultural route, a more effective and compelling tourism product can be generated through a common narrative, strategies, human resources, and management infrastructure (UNWTO, 2015, p. 52).

According to Gaweł, evaluating cultural routes merely as tourism products poses several problems (Gaweł, 2011, pp. 30-32). Examples of cultural, environmental, and social issues include cultural degeneration, damage to cultural and natural values resulting from overuse or misuse, depletion of resources, increased environmental pollution, and gentrification and the displacement of local residents due to excessive increases in real estate prices and the rising costs of basic necessities. Conversely, significant opportunities may arise by fostering heritage conservation awareness, providing economic support for conservation activities, strengthening regulatory and monitoring processes, and promoting the sustainability of culture and tourism (Karataş, 2025, pp. 23-25).

At present, the development of cultural routes has emerged as one of the most widely adopted approaches in the planning of cultural tourism. Rooted in experiences of movement, exploration of diverse places, and knowledge acquisition, heritage routes are supported in various contexts by public institutions as well as non-profit national and international organizations, serving a wide range of objectives.

Cultural Routes from a Heritage Perspective

In the past, heritage management approaches primarily focused on the conservation of physical resources. However, the concept of "integrated conservation," prominently emphasized in the Amsterdam Declaration (1975), led to a shift from this approach toward a more comprehensive and multidimensional effort. The expansion of the scope of the heritage concept has also played a decisive role in this transformation.

Although advancing technical and technological capabilities have facilitated physical conservation, ensuring the sustainability of protection in areas possessing cultural heritage necessitates the pursuit of new solutions, broad participation in governance processes, societal support, and the integration of heritage with everyday social life (de la Torre, MacLean, Mason, & Myers, 2005, pp. 4-5). To achieve this integration, sustainability must be targeted across social, administrative, legal, physical, technical, and economic dimensions (ICOMOS, 1975). The resulting synergy should be aimed at contributing to sustainability in social, cultural, economic, and ecological terms.

UNESCO emphasizes the necessity of a qualified management approach for the protection and promotion of cultural heritage routes. It highlights the importance of keeping the level of tourism activities along these routes under control, as well as the imperative participation of local communities living in the regions through which the routes pass as key stakeholders in the process. Furthermore, the need to integrate land-use planning policies in line with sustainable development goals is also underscored (World Heritage Committee, 1994).

Dataset and Variables of the Cultural Routes

Launched in 1987, the Cultural Routes of the Council of Europe programme aims to promote intercultural dialogue, support the protection and promotion of natural and cultural heritage, and, in particular, foster cooperation and advance the notion of a common European heritage (Council of Europe, 2025b; Martens, 2022).

Established in 2010 to strengthen the programme, the Enlarged Partial Agreement on Cultural Routes of the Council of Europe (EPA) has developed the criteria for the Cultural Route of the Council of Europe certification (Council of Europe, 2025b).

These criteria are as follows (Council of Europe, 2025b):

- *Involve a theme that is representative of European values and common to at least three countries in Europe,*
- *be the subject of transnational, multidisciplinary scientific research,*
- *enhance European memory, history and heritage and contribute to interpretation of Europe's present-day diversity,*
- *support cultural and educational exchanges for young people,*

- *develop exemplary and innovative projects in the field of cultural tourism and sustainable cultural development,*
- *develop tourist products and services aimed at different groups.*

In this section, drawing on the approach proposed in the UNWTO Report (2015), the 49 Cultural Routes certified by the Council of Europe are analysed under seven variables (Council of Europe, 2025a): number of countries, spatial categories, thematic source, key theme, design structure, main purpose, and certification years (Table Appendix 1).

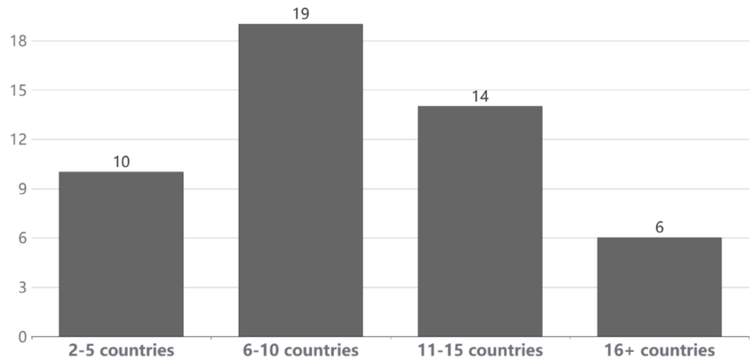
Number of Countries: The Council of Europe Cultural Routes extend across 45 Council of Europe member states and 12 non-member countries[3] (Council of Europe, 2025c).

According to 2025 data, France and Italy host the highest number of routes among Council of Europe member states, with 36 routes each; they are followed by Germany with 30 routes, Spain with 29 routes, and Poland with 21 routes (Council of Europe, 2025c).

Graph 1 presents the number of countries covered by each Cultural Route. Accordingly, routes spanning 6-10 countries constitute the largest group (19), followed by those spanning 11-15 countries (14) and 2-5 countries (10), while only six routes involve 16 or more countries (Council of Europe, 2025c).

[3] Among the Council of Europe member states, Monaco does not yet host a certified Cultural Route; similarly, no certified route has yet been established in the Holy See, despite its status as a Party to the Enlarged Partial Agreement on Cultural Routes of the Council of Europe (Council of Europe, 2025c).

Graph 1. Number of Countries Participating in Cultural Routes.



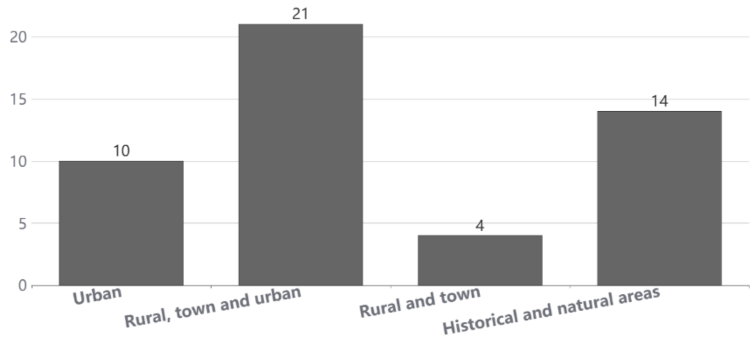
Source: Prepared by E. Karataş based on data in Table Appendix 1.

Based on the spatial overlap presented in Graph 1 and the 2025 dataset, certified Cultural Routes appear to be concentrated in the Mediterranean Basin and Western Europe, reflecting the combined influence of geographical, historical, cultural, and political factors, while Eastern and Northern European countries participate in comparatively fewer routes. Most routes extending beyond Europe predominantly include Mediterranean countries such as Algeria, Egypt, Jordan, and Morocco (Council of Europe, 2025c).

Spatial Categories: In this study, the routes are examined under four spatial categories: (1) urban, (2) rural, town and urban, (3) rural and town, and (4) historical and natural areas.

Of the 49 cases analysed, 21 fall within the "rural, town and urban" category, which constitutes the most prominent group. In addition, 14 routes are classified as "historical and natural areas", 10 as "urban", and 4 as "rural and town" (Graph 2).

Graph 2 Spatial Categories of Cultural Routes.



Source: Prepared by E. Karataş based on data in Table Appendix 1.

Thematic Source: Within the scope of the study, Cultural Routes are classified into two categories; "historical" and "fictional", according to the source of their themes in relation to physical use.

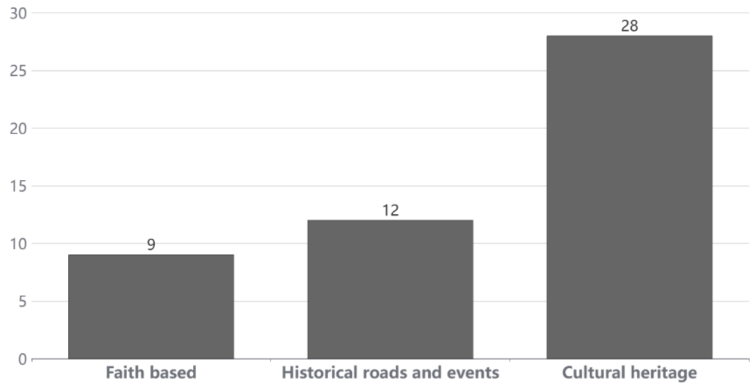
While historical routes are underpinned by strong historical linkages, fictional routes are brought together primarily through thematic similarities and narrative constructions. Among the 49 routes certified by the Council of Europe, 37 are identified as fictional and 12 as historical.

Key Theme: Each certified case is associated with a key theme and, in most instances, additional supporting themes. The key theme provides the overarching framework of the cultural route, and the tourism products offered within the route are generally aligned with this thematic framing. Supporting themes, by contrast, appear to be shaped by the meanings and modes of use that emerge from the spatial experiences provided by the routes, thereby complementing and enriching the key theme.

The key themes of the 49 cases were categorised. "Cultural heritage" emerges as the key theme in 28 cases, followed by "historical road and events" in 12 cases and "faith based" themes in

9 cases. This distribution indicates that cultural heritage constitutes the most dominant thematic framework within the programme, whereas more niche thematic domains remain comparatively underrepresented (Graph 3).

Graph 3 Key Themes of Cultural Routes.



Source: Prepared by E. Karataş based on data in Table Appendix 1.

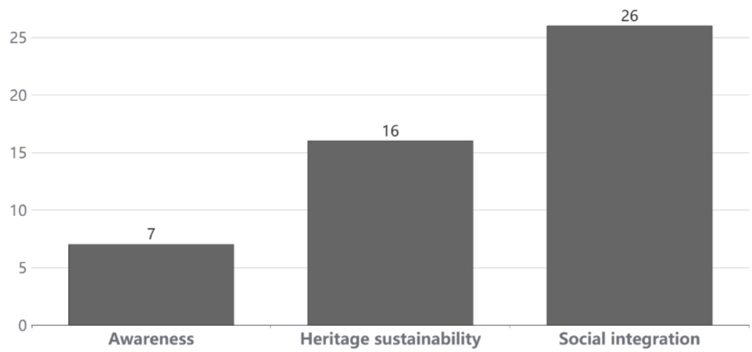
Design Structure: The design structures of Cultural Routes are classified into two types: “linear” and “network”. Linear routes have defined starting and ending points, with destinations typically arranged along a continuous corridor. Network routes, by contrast, are multi-nodal configurations without a fixed origin or terminus, in which destinations are distributed across a wider geography in the form of a network.

Within the scope of this study, of the 49 cases analysed, 14 are identified as linear, whereas 35 exhibit a network structure.

Main Purpose: Cultural Routes are employed by the Council of Europe to serve a range of objectives. Each route is characterised by a primary aim, alongside secondary aims shaped by the route’s scope and contextual setting.

Graph 4 illustrates the main purposes of the 49 routes analysed. Accordingly, social integration is identified as the primary aim in 26 cases, heritage sustainability in 16 cases, and awareness-raising in 7 cases.

Graph 4 Main Objectives of Cultural Routes.

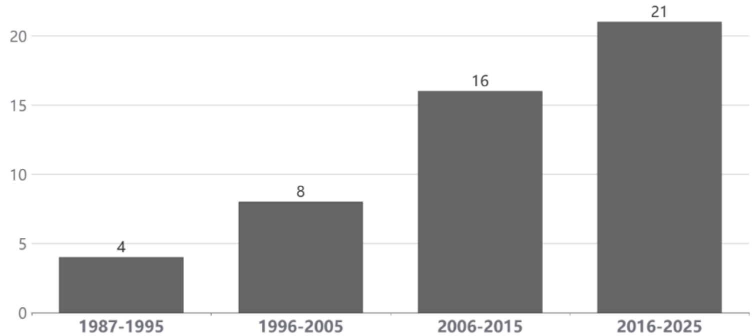


Source: Prepared by E. Karataş based on data in Table Appendix 1.

Certification Years: The Council of Europe certified cases are categorised by decade.

Graph 5 presents the number of Cultural Routes certified across these ten-year periods. The first certified case is the Routes of Santiago de Compostela in 1987, which also represents the only route certified during the 1986–1990 period. Overall, the figure indicates a steady increase in the number of certifications over time. The COE certified 4 routes in the first decade, 8 in the second, 16 in the third, and 21 in the fourth.

Graph 5 Cultural Routes Certified by Decadal Periods.



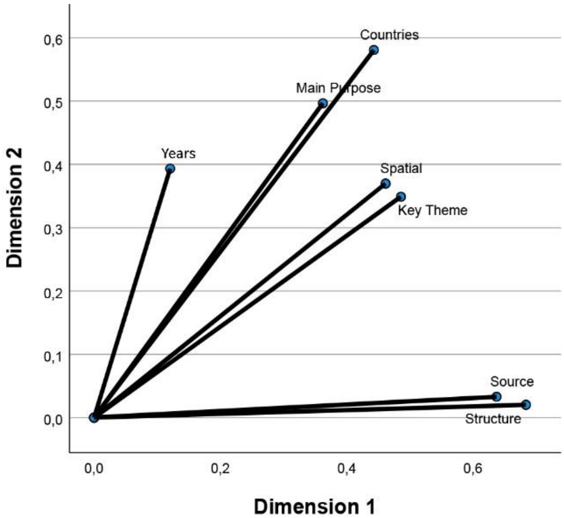
Source: Prepared by E. Karataş based on data in Table Appendix 1.

Results

In this study, the data of the Cultural Routes of the Council of Europe programme examples, classified into seven variables and twenty-two category levels, are presented in Table Appendix 1. The data obtained from this table were subjected to Multiple Correspondence Analysis (MCA) using IBM SPSS Statistics 27. Through this analysis, the profiles and combinations of the 49 routes certified up to the end of 2025 were examined, with the aim of identifying similar and divergent cases as well as clusters.

The discrimination measures plot illustrating the contributions of variables to the dimensions reveals that the two dimensions are characterized by different logics of differentiation. Accordingly, Dimension 1 is primarily defined by the categories of design structure, thematic source, key theme, and spatial categories, whereas Dimension 2 is mainly defined by the categories of number of countries, main purpose, and certification years (Graph 6).

Graph 6. Discrimination Measures.



Source: Prepared using IBM SPSS Statistics 27.

The matrix of correlations of the transformed variables indicates that the categories of structure, source, and key theme are strongly interrelated (Graph 7).

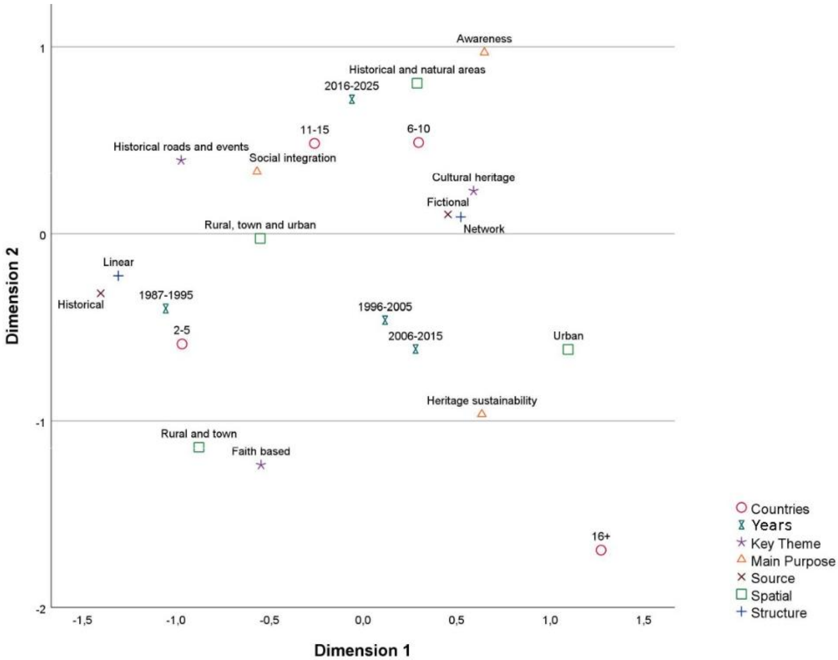
Graph 7. Correlations of Transformed Variables.

	Countries	Spatial	Source	Key Theme	Structure	Main Purpose	Years
Countries	1,000	,500	,445	,221	,383	,365	,212
Spatial	,500	1,000	,412	,298	,465	,297	,164
Source	,445	,412	1,000	,571	,690	,250	,158
Key Theme	,221	,298	,571	1,000	,541	,374	,147
Structure	,383	,465	,690	,541	1,000	,414	,187
Main Purpose	,365	,297	,250	,374	,414	1,000	,207
Years	,212	,164	,158	,147	,187	,207	1,000

Source: Prepared using IBM SPSS Statistics 27.

The joint plot of category points illustrates the configuration patterns of the category levels (Graph 8).

Graph 8. Joint Plot of Category Points.



Source: Prepared using IBM SPSS Statistics 27.

The cluster located in the mid-left section of Graph 8, consisting of the categories "linear, historical, 1987-1995, 2-5," indicates that the early examples of the programme were generally linear and historically grounded, covering a limited number of countries.

The cluster positioned in the upper-right section, defined by "cultural heritage, fictional, network," emphasizes that examples with a cultural heritage key theme are generally characterized by fictional narratives and network-based structures.

The convergence observed in the upper part of the graph around the categories "awareness, historical and natural areas, 6-10, 11-15, 2016-2025" suggests that routes certified in the most recent period tend to be awareness-oriented, utilize historical and natural areas, and exhibit a relatively higher degree of internationalization.

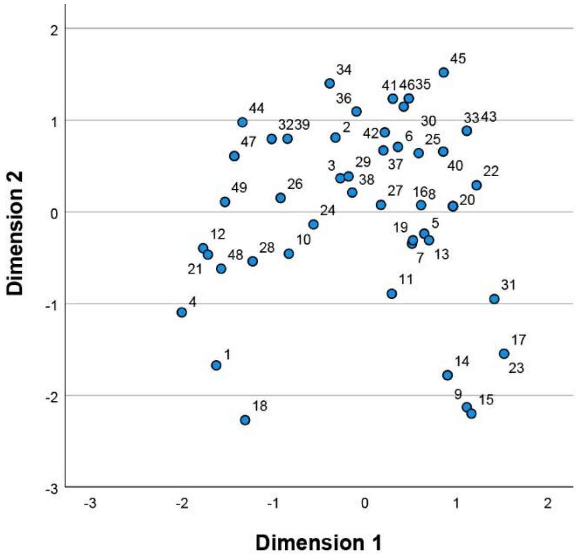
The positioning of the category levels “heritage sustainability, urban, 1996-2005, 2006-2015” in the lower section of the graph indicates that, during the middle period, heritage-focused objectives and an urban scale were more prominent.

The co-location of the “faith based” level with the “historical” and “linear” categories on the same side of the graph demonstrates that faith-themed route examples are generally shaped by historically grounded narratives and a linear itinerary logic. Moreover, the proximity of the “faith based” level to the “rural and town” category indicates that this theme predominantly draws upon rural and small-settlement contexts.

In Graph 8, the “16+” category level of the “number of countries” variable is clearly separated from the other country ranges. This suggests that routes with a very high level of international spread (16+) constitute a distinct profile in which objectives and spatial context components also diverge.

In Graph 9, the object points plot represents the 49 Cultural Routes as individual points. The proximity between case points indicates similarities in cultural route profiles based on the defined category levels, whereas greater distances reflect divergence or outlier characteristics.

Graph 9 Object Points Labeled by Case Numbers.



Source: Prepared using IBM SPSS Statistics 27.

In Graph 9, the majority of the cases are observed to cluster close to the centre, while a number of examples clearly diverge from this cluster. The differentiated cases indicate that some routes fall outside the dominant profile in terms of their variable combinations, suggesting that distinct governance and productization logics can coexist within the programme across different periods.

Discussion and Conclusions

This study examines the 49 Cultural Routes certified under the Cultural Routes of the Council of Europe programme by the end of 2025 through a statistical analysis method, aiming to reveal the programme's development and prevailing trends. The accelerating increase in the programme's diffusion over time confirms its growing impact and influence. In the initial period (1987-1995), Cultural Routes were generally grounded in historical foundations, followed linear itineraries, and covered a limited number of countries. Over time, this approach has progressively given way to multi-centred network structures shaped around fictional themes and niche topics. This shift confirms that the concept of the route has evolved beyond a purely physical transportation corridor into a form of "boundary object" and "thematic network" that integrates tangible and intangible heritage (Del Chiappa, Bregoli, & Kim, 2019).

The analysis results indicate that the primary objectives of the routes have diversified over time. While the first three periods (1987-1995, 1996-2005, and 2006-2015) were predominantly oriented toward heritage sustainability, the last decade (2016-2025) has seen "awareness" and "social integration" emerge as leading objectives. This trend demonstrates that cultural routes are positioned not only as tourism products, site management tools, or instruments of cultural heritage conservation, but also within a broader framework of cultural and political governance aimed at transmitting European values, strengthening a sense of Europeanness, and enhancing social awareness.

However, some characteristics that enable the Council of Europe's Cultural Routes to function as transnational heritage networks promoting common European values are also subject to criticism. According to Martens (2022), their configuration as multi-nodal networks instead of clearly defined itineraries is often considered to result in a limited "route" experience and a weakly connected European narrative.

Faith and cultural heritage continue to constitute the most dominant key themes of European heritage, while niche fields such as gastronomy, health, and landscape remain represented to a limited extent. The proximity of faith-based routes to the historical, linear, rural, and small-town category levels indicates a consistent profile in which religious heritage is typically articulated through historically grounded, linear itineraries associated with the landscapes of small settlements and rural areas.

Correlation patterns reveal a strong interrelationship among design structure, thematic source, and main purpose. This finding confirms that design choices, thematic foundations, and route objectives tend to emerge in conjunction rather than as independent variables.

The object point map shows that many routes cluster near the centre, while a small number clearly diverge from this central tendency. This pattern confirms that the programme accommodates both dominant configurations and differentiated route models.

In summary, this study addresses the 39-year transformation of the Cultural Routes of the Council of Europe programme. The findings indicate that the programme has followed a developmental trajectory evolving from historical and linear itineraries toward fictional and multi-centred network structures. This process also reflects a shift in objectives, extending from heritage sustainability toward social awareness and social integration. Accordingly, the programme does not regard cultural routes solely as tools for the protection and promotion of cultural heritage, but also operates as a multi-layered governance mechanism aimed at circulating European values and fostering a shared sense of Europeanness. In this respect, the programme offers a distinctive model that transforms place-based cultural narratives into a normative and social policy instrument at the European scale.

Table Appendix 1 Analysis of Council of Europe–Certified Cultural Routes.

No	Name	Ctries.	Spatial	Source	Key Theme	Structure	Main Purpose	Years
1	Santiago de Compostela Pilgrim Routes	2	Rural, town and urban	Historical	Faith based	Linear	Heritage sustainability	1987
2	The Hansa	9	Historical and natural areas	Fictional	Historical roads and events	Network	Social integration	1991
3	Viking Route	15	Rural, town and urban	Fictional	Cultural heritage	Network	Social integration	1993
4	Via Francigena	2	Rural, town and urban	Historical	Faith based	Linear	Social integration	1994
5	Routes of El Legado Andalusí	6	Rural, town and urban	Fictional	Cultural heritage	Network	Heritage sustainability	1997
6	Phoenicians' Route	14	Historical and natural areas	Fictional	Cultural heritage	Network	Social integration	2003
7	Iron Route in the Pyrenees	3	Historical and natural areas	Fictional	Cultural heritage	Network	Heritage sustainability	2003
8	European Mozart Ways	11	Urban	Fictional	Cultural heritage	Network	Social integration	2004
9	European Route of Jewish Heritage	24	Urban	Fictional	Faith based	Network	Heritage sustainability	2004
10	Saint Martin of Tours Route	12	Rural, town and urban	Fictional	Faith based	Linear	Social integration	2005
11	Cluniac Sites in Europe	8	Rural, town and urban	Fictional	Faith based	Network	Heritage sustainability	2005
12	Via Regia	5	Rural, town and urban	Historical	Historical roads and events	Linear	Social integration	2005
13	Transromanica	10	Rural, town and urban	Fictional	Cultural heritage	Network	Heritage sustainability	2007
14	Iter Vitis Route	22	Rural and town	Fictional	Cultural heritage	Network	Heritage sustainability	2009

No	Name	Ctries.	Spatial	Source	Key Theme	Structure	Main Purpose	Years
15	European Cemeteries Route	21	Urban	Fictional	Faith based	Network	Heritage sustainability	2010
16	Prehistoric Rock Art Trails	9	Historical and natural areas	Fictional	Cultural heritage	Network	Heritage sustainability	2010
17	Route of Historic Thermal Towns	17	Urban	Fictional	Cultural heritage	Network	Heritage sustainability	2010
18	Route of Saint Olav Ways	5	Rural and town	Historical	Faith based	Linear	Heritage sustainability	2010
19	European Route of Ceramics	14	Rural, town and urban	Fictional	Cultural heritage	Network	Heritage sustainability	2012
20	European Route of Megalithic Culture	10	Historical and natural areas	Fictional	Cultural heritage	Network	Heritage sustainability	2013
21	Huguenot and Waldensian Trail	4	Rural, town and urban	Historical	Historical roads and events	Linear	Social integration	2013
22	ATRIUM	6	Urban	Fictional	Cultural heritage	Network	Awareness	2014
23	Réseau Art Nouveau Network	16	Urban	Fictional	Cultural heritage	Network	Heritage sustainability	2014
24	Via Habsburg	4	Rural, town and urban	Fictional	Historical roads and events	Network	Social integration	2014
25	Roman Emperors and Danube Wine Route	10	Historical and natural areas	Fictional	Cultural heritage	Network	Social integration	2015
26	European Routes of Emperor Charles V	13	Rural, town and urban	Historical	Historical roads and events	Network	Social integration	2015
27	Destination Napoleon	12	Urban	Fictional	Historical roads and events	Network	Social integration	2015
28	In the Footsteps of Robert Louis Stevenson	3	Rural, town and urban	Historical	Cultural heritage	Linear	Social integration	2015
29	Fortified Towns of the Grande Region	3	Rural, town and urban	Fictional	Cultural heritage	Network	Social integration	2016

No	Name	Ctries.	Spatial	Source	Key Theme	Structure	Main Purpose	Years
30	Impressionnisms Routes	12	Rural, town and urban	Fictional	Cultural heritage	Network	Awareness	2018
31	European Route of Industrial Heritage	28	Urban	Fictional	Cultural heritage	Network	Heritage sustainability	2019
32	Iron Curtain Trail-EuroVelo 13	14	Rural, town and urban	Fictional	Historical roads and events	Linear	Social integration	2019
33	Le Corbusier Destinations: Architectural Promenades	6	Urban	Fictional	Cultural heritage	Network	Awareness	2019
34	Liberation Route Europe	12	Historical and natural areas	Historical	Historical roads and events	Network	Awareness	2019
35	European Route of Historic Gardens	10	Historical and natural areas	Fictional	Cultural heritage	Network	Social integration	2020
36	Aeneas Route	7	Historical and natural areas	Fictional	Cultural heritage	Linear	Social integration	2021
37	Alvar Aalto Route	5	Rural, town and urban	Fictional	Cultural heritage	Network	Awareness	2021
38	Cyril and Methodius Route	10	Rural, town and urban	Fictional	Faith based	Network	Social integration	2021
39	European Route d'Artagnan	6	Rural, town and urban	Fictional	Historical roads and events	Linear	Social integration	2021
40	Iron Age Danube Route	8	Historical and natural areas	Fictional	Cultural heritage	Network	Heritage sustainability	2021
41	Historic Cafés Route	15	Historical and natural areas	Fictional	Cultural heritage	Network	Social integration	2022
42	European Fairy Tale Route	8	Rural, town and urban	Fictional	Cultural heritage	Network	Social integration	2022
43	Women Writers Route	7	Urban	Fictional	Cultural heritage	Network	Awareness	2022

No	Name	Ctries.	Spatial	Source	Key Theme	Structure	Main Purpose	Years
44	Transhumance trails	11	Historical and natural areas	Historical	Historical roads and events	Linear	Social integration	2023
45	Leonardo Da Vinci Route	6	Historical and natural areas	Fictional	Cultural heritage	Network	Awareness	2024
46	Historic Pharmacies & Medicinal Gardens Route	13	Historical and natural areas	Fictional	Cultural heritage	Network	Social integration	2024
47	Romea Strata	7	Rural, town and urban	Historical	Historical roads and events	Linear	Social integration	2025
48	Saint Francis Ways	13	Rural and town	Historical	Faith based	Linear	Social integration	2025
49	Pyrenean Freedom Routes	10	Rural and town	Historical	Historical roads and events	Linear	Social integration	2025

Source: Compiled by the author using information obtained from: https://www.coe.int/en/web/cultural-routes (accessed on December 2025).

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CHAPTER 5

EXAMINATION OF ACCESSIBILITY IN CITY PARKS IN KONYA

1. EMİNE YILDIZ KUYRUKÇU[1]
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Introduction

Modern urban life requires individuals to evaluate their relationship with the physical environment not only through the lenses of aesthetics or functionality but also through the frameworks of accessibility, inclusivity, equality, and human rights. Accessibility is crucial for individuals with disabilities, the elderly, children, pregnant women, and those with temporary mobility limitations.

It refers to the ability of users to benefit from urban spaces independently, safely, and with dignity. Physical, sensory, mental, or psychosocial limitations encountered in daily life significantly affect individuals' relationships with space, directly influencing the level of inclusivity in spatial design. In Türkiye, equal participation of

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people with disabilities in urban life is not only a legal requirement but also a social responsibility.

Public green spaces and urban parks are essential urban open areas where individuals can connect with nature, engage in social interaction, and improve their physical and psychological well-being. However, the fact that many park designs are still shaped according to the “general user” profile leads to the neglect of different needs groups and brings with it various accessibility problems (Imrie, 2012; Pineda, 2020). These problems not only create a physical barrier but also deepen social exclusion, limiting individuals' participation in urban life. Current research indicates that accessible open spaces play a crucial role in reducing stress, promoting physical activity, and enhancing social interaction (Lee & Maheswaran, 2011; Zhang et al., 2025).

In international literature, the concept of accessibility is considered not merely as an arrangement to meet the spatial needs of individuals with disabilities, but as a holistic design approach that encompasses all segments of society, improves quality of life, and supports social equality. Accessible environments are recognized as enabling individuals to move independently, participate in public life, and strengthen their relationship with space; in this respect, they are considered one of the fundamental components of sustainable and inclusive cities (Steinfeld & Maisel, 2012). Universal Design, which forms the theoretical basis of this approach, was first defined by architect Ronald L. Mace as “designing environments that accommodate the widest possible range of users without requiring special adaptations”.

Universal Design is defined as “designing products and environments that the masses can use” (Story et al., 1998). Universal Design addresses disability not as a personal deficiency of the individual, but as a problem arising from the inadequacy of environmental arrangements and redefines the design process from this perspective. Developed by Ronald Mace and North Carolina State University, the Universal Design Principles are structured around seven fundamental principles with a wide range of applications, from public spaces to housing, from product design to urban furnishings. These principles aim for spaces to be not only accessible but also safe, legible, flexible, and user-friendly (Connell, 1997; Steinfeld & Maisel, 2012).

- *Equitable Use,* this principle means that the designed environment should be usable fairly and equally by all users without discrimination. Instead of creating separate and secondary solutions for individuals with disabilities, this principle aims to provide a common and inclusive user experience for everyone.
- *Flexibility in Use,* this principle refers to the adaptability of space to different user preferences, skill levels, and mobility. It emphasizes flexible design decisions that allow individuals to use the space at their own pace and according to their own needs.
- *Simple and Intuitive Use,* the aim is to ensure that the way a space is used is easily understandable, regardless of user experience, level of knowledge, or language skills. Creating clear and readable spatial organizations, rather than complex wayfinding systems or information overload, forms the basis of this principle.
- *Perceptible Information,* this principle means that necessary information about a space should be perceptible by all users through visual, auditory, or tactile means. Designing guidance, warning, and information systems that appeal to multiple senses is central to this principle, especially for individuals with visual or hearing impairments.

- *Tolerance for Error* stipulates that the space should be arranged in a way that minimizes risks in the event of potential user errors. Developing safe design solutions to prevent serious consequences from situations such as falls, collisions, or misorientation is considered within the scope of this principle.
- *Low Physical Effort* means that the design should require minimal physical effort for its use. Limiting long ramps, heavy doorways, or equipment requiring high physical strength falls within the scope of this principle.
- *Size and Space for Approach and Use:* The aim is to provide adequate movement and maneuvering space for everyone, including wheelchair users, stroller users, and all users requiring assistive devices. This principle necessitates that spatial dimensions be determined, taking into account the human scale and user diversity.

When these seven principles are considered together, it becomes clear that Universal Design addresses not only physical accessibility but also the perceptibility, safety, and usability of space through a holistic approach. This framework encompasses public open spaces. It provides a strong analytical basis for evaluating areas and allows for a comparative examination of the accessibility performance of parks from the perspective of different user groups.

Park accessibility is also a critical issue in the context of social justice and spatial equality. Maruani and Amit-Cohen (2007) highlight the role of parks in social integration, while the World Health Organization (WHO, 2016) comprehensively demonstrates the impacts of open space accessibility on urban health and social well-being. Recent studies provide strong evidence that accessible parks significantly improve the quality of life, particularly for vulnerable user groups (Rigolon et al., 2018; Shan & He, 2025).

While accessibility has gained increasing importance in Türkiye in recent years, shortcomings in its implementation in public open spaces persist. Various problems are observed, particularly in parks and recreation areas, regarding user guidance, mobility, and spatial safety. Literature research reveals that many public parks still contain physical, visual, and spatial barriers; ramps, surface transitions, circulation axes, and directional elements are often not designed to a sufficient standard (Aykal et al., 2017; Aylan & Şalvarcı, 2018; Bekci & Sipahi, 2023). These deficiencies directly affect not only individuals with disabilities but also a wide range of users, including the elderly, children, pregnant women, and individuals with temporary mobility limitations.

In this context, evaluating the accessibility level of public parks has become a critical requirement for improving the quality of the physical environment and strengthening social inclusion. Universal Design Principles aim to create spaces that all individuals can use equally, safely, intuitively, and comfortably. The principles of equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use provide a strong methodological foundation for the analysis and evaluation of public open spaces (Steinfeld & Maisel, 2012).

Material And Method

This study evaluated the accessibility levels of Kalehan Ecdat Park, Olympic Park, and 80 Binde Devr-i Alem Park in Konya. The Universal Design Principles were used as the basis for the review; the Accessibility Guide published by the Ministry of Family and Social Services, which provides current criteria for public spaces in Turkey, was used as a reference. The parks' differing characteristics in terms of theme, scale, landscape character, and user profile allowed for a comparative analysis of their accessibility performance.

The research included on-site observations in all three parks. Photographic documentation and spatial analysis methods were applied. During this process, accessibility components were systematically examined; furthermore, qualitative data regarding park navigation, safety, guidance, and comfort experiences were obtained through short, unstructured interviews with park users. Interviews considered individuals with disabilities, elderly users, families with children, and young users.

The accessibility assessment of the parks was carried out under the headings of park entrances, parking areas, pedestrian paths and circulation, urban equipment (lighting, trash cans, seating units, etc.), and landscaping and wayfinding. A descriptive analysis approach was adopted in the evaluation process. Through checklists prepared for each park, accessibility components were classified as "adequate", "partially adequate" and "not adequate", and the differences between the parks were presented comparatively.

Examining The Accessibility of Parks in Konya

In current literature, accessibility in parks is considered not only as a spatial arrangement for individuals with disabilities, but also as a fundamental spatial quality that enables all users to use public spaces safely, independently, and comfortably (Steinfeld & Maisel, 2012). This approach demonstrates that accessible public open spaces increase user satisfaction and the frequency of use by different user groups (UN-Habitat, 2020).

The findings of the research show that the accessibility levels of parks differ based on spatial components. In particular, factors such as the continuity and width of walkways, the location and slope of ramps, the accessibility of seating areas, and the clarity of directional systems are seen as decisive in the user experience. The literature also emphasizes that deficiencies in these components affect not only wheelchair users but also elderly individuals, families with children, and users with temporary mobility limitations (WHO, 2016).

In this context, accessibility is considered not as a regulation aimed at a specific user group, but rather as a holistic design criterion that determines the overall quality of use of parks. Below, the accessibility characteristics of *Kalehan Ecdat Park*, *Olympic Park*, and *80 Binde Devr-i Âlem Park* in Konya are examined separately in accordance with the determined spatial components.

Kalehan Ecdat Park

Kalehan Ecdat Park, which opened in 2017, has approximately with its area of approximately 110,000 m² and a pond surface of 12,500 m²; it is among Konya's large-scale public open spaces (Figure 1). The park's spatial design includes various usage areas consisting of walking paths, large lawns, water features, seating areas, and semi-shaded resting places. This design, supported by historical figures, miniature structures, and cultural representations, allows the park to be used not only for recreation but also as a cultural experience space.

Figure 1. View of Kalehan Ecdat Park

Extensive green spaces and natural landscape elements enhance both the aesthetic and ecological value of the park, while offering a flexible variety of uses appealing to different age and user groups (Figure 2). The studies conducted emphasize that sustainable landscape practices strengthen the ecological performance of public open spaces and increase environmental awareness (Kuyrukçu & Akıllı, 2023).

Figure 2. A bird's-eye view of Kalehan Ecdat Park

Park Entrances

Kalehan Ecdat Park is characterized by a spatial organization defined by a controlled-entry system. Two main pedestrian entrances, located at the north and south ends and themed around Ottoman and Seljuk architecture, provide accessible entry points for diverse user groups, with wide, stair-free designs (Figure 3). The entrance openings, approximately 220 cm wide, provide sufficient passage space for wheelchair users and stroller users. The principles of **equitable use, low physical effort,** and **size and space for approach and use** largely meet.

Guidelines and an open spatial design used in the entrance areas make it easier for users to navigate into the park, **simple and intuitive to use,** which supports this principle. However, the fact that directional elements are predominantly visual in nature, **perceptible information**. This shows that the principle is only partially met, especially for visually impaired users. Furthermore, the limited number of supplementary guidance elements reduced the margin of error, **tolerance for error**. This reveals that the principle has not been fully achieved.

While the VIP and service entrances in the park contribute to spatial and functional diversity, these areas are geared towards specific user group **flexibility in use**. This shows that the principle is met to a limited extent. In general, park entrances, equitable and physical accessibility are strong, in terms of **perceptible information, tolerance for error,** and **flexibility in use**. However, it does have features that need to be improved (Figure 4).

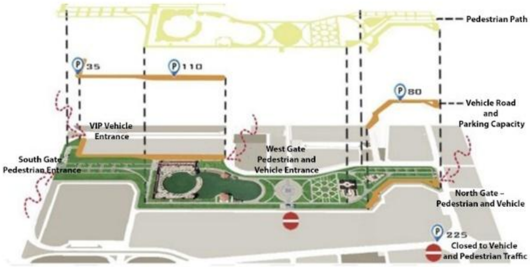
Figure 3. Kalehan Ecdat Park Ottoman Entrance.

Figure 4. Kalehan Ecdat Park Vehicle Entrance.

Parking Area

The parking areas of Kalehan Ecdat Park are located near different entrance points of the park and are arranged with varying capacities (Figure 5). The small parking lot with a capacity of 8 vehicles, located approximately 5 meters from the main pedestrian entrance, does not offer equal accessibility for all users despite its advantageous location, due to the lack of parking spaces reserved for disabled individuals. This situation requires **equitable use**. This indicates that the principle is not fully met. However, the proximity of the parking area to the entrances and access to the parking area require **low physical effort**. This constitutes a potential advantage in this respect.

Figure 5. Parking areas of Kalehan Ecdat Park



Kaynak: Dağ Çınaroğlu, 2019

Located in a parking area connected to the main vehicle entrance and with a capacity of 80 vehicles, the 20 extended parking spaces, approximately 400 cm wide, provide ample maneuvering space for wheelchair users, **size and space for approach and use** (Figure 6). This arrangement allows users to exert less physical effort during the transition from vehicular to pedestrian circulation. However, the limited number of guidance and information elements in this area, **perceptible information**. This shows that the principle has only been partially met.

Figure 6. Kalehan Ecdat Park pedestrian entrance parking lot.

The parking areas with capacities of 35 and 110 vehicles, located near the VIP entrance, and the large parking area with a capacity of 225 vehicles, offer limited accessibility, especially for users with mobility limitations, due to their distance from the main areas of the park. This situation affects **flexibility in use**, the principle for all user groups. Furthermore, the limited number of crossing elements that strengthen pedestrian-vehicle relations and the repetition of directions that reduce the risk of errors, **simple and intuitive to use** with **tolerance for error**. This shows that the principles are only partially met.

Overall, the parking areas of Kalehan Ecdat Park suitable size and space with low physical effort. While exhibiting positive characteristics in certain areas in terms of its principles, equitable use, perceptible information, and flexibility in use, it has aspects that need improvement in terms of its principles.

Pedestrian Pathways and Circulation

The circulation system of Kalehan Ecdat Park creates a continuous network of movement throughout the park via wide pedestrian axes, intermediate walkways, and ramped connections. The main pedestrian axes are approximately 540 cm, and the intermediate walkways are 280 cm. This width allows wheelchair users, families with children, and slow-paced walkers to move around the park simultaneously and comfortably; this situation promotes **equitable use** and **flexibility in use**. The clear and legible design of pedestrian paths allows users to easily perceive their direction. **Simple and intuitive to use**, it supports the principle.

Transitions between different levels throughout the park are approximately Ramps with %7 inclines. This is achieved through a system that allows users to progress without expending excessive physical effort, with **low physical effort**. It contributes to the principle. Measured on stairs 17 cm quay height, approximately 75 cm step depth, and 155 cm ladder width. This provides a comfortable and safe working surface for a wide range of users. These dimensions demonstrate that the stairs meet basic ergonomic requirements (Figure 7).

Figure 7. Ramps and stairs of Kalehan Ecdat Park.

Guidelines located at the start and end points of the walking paths increase the visibility of the route. The **perceptible information** principle partially supports. However, the lack of continuity of these directional elements throughout the park's circulation route creates limitations in terms of spatial interpretation. Nevertheless, along the ramps and stairs. Absence of railings and handrails poses a safety risk, especially for elderly individuals, users with balance problems, and families with children. This shows that the **tolerance for error** principle has not been adequately fulfilled (Figure 8).

Figure 8. Main walking axes of Kalehan Ecdat Park.

Overall, the circulation system of Kalehan Ecdat Park successfully meets some principles of universal design in terms of road widths, ramp slopes, and stair dimensions, particularly in the context of handrails and continuity of guidance. **Equitable use**, **flexibility in use,** and **tolerance for error.** It has aspects that need improvement in terms of its principles.

Urban Equipment (Lighting, Trash Cans, etc.)

The urban equipment located in Kalehan Ecdat Park, in general, is designed in a way that will support the park's circulatory system. They are positioned along the walking paths and outside the circulation area. The lighting poles do not interrupt user movement and **equitable use** with **low physical effort**. It offers a positive arrangement in terms of its principles. Approximately 350 cm Lighting elements with a certain height offer a size that can provide sufficient light distribution while also supporting user safety by reducing the risk of physical contact and impact. However, within the scope of this study, night observation was not possible. This has limited the evaluation of critical accessibility criteria such as homogeneity of lighting levels, glare effect, and shadow formation. Therefore, the principle of **perceptible information** has been partially met in this context (Figure 9).

Figure 9. Kalehan Ecdat Park lighting poles.

While trash cans along walkways are functional in terms of waste management, the lack of guidelines or warning surfaces poses a risk of collision, particularly for visually impaired individuals. This situation leads to the equipment not being perceived spatially intuitively enough. This is inconsistent with the principles of **perceptible information** and **tolerance for error**. Overall, the park's urban layout offers a settlement strategy that does not disrupt the flow of circulation. However, due to the lack of sensory guidance elements, it has aspects that need improvement in terms of **flexibility in use** and **equitable use** principles (Figure 10).

Figure 10. Trash cans in Kalehan Ecdat Park.

Landscape and Wayfinding

The yellow guidelines and directional signs along the walking paths demonstrate that the park offers a certain level of support for wayfinding and partially fulfill the principle of **simple and intuitive use**. However, this navigation system relies primarily on visual elements and is not supported by auditory or tactile aids. This results in limited accessibility in terms of **equitable use** and **flexibility in use** for all user groups. This situation reveals that the principle of **perceptible information** is not adequately provided, especially for visually impaired individuals (Figure 11).

Figure 11. Landscape design of Kalehan Ecdat Park.

The large pond is one of the park's important landscape components. Despite being a strong recreational focal point, the inadequacy of safety arrangements around the pond poses a significant accessibility problem. The fact that the movable chain railings around the pond are easily overcome and lack continuity in some sections increases the risk of falls, especially for children and visually impaired individuals. **Tolerance for error** and **equitable use** are incompatible with the principles. These shortcomings also require users to expend more physical attention and effort in the space. This reveals that the principle of **low physical effort** is only met to a limited extent.

Accordingly, the park’s entrances, parking areas, pedestrian walkways, urban equipment, landscaping, and wayfinding components were evaluated within the framework of Universal Design Principles, and the findings are presented in Table 1.

Table 1. Evaluation of Kalehan Ecdat Park according to Universal Design Principles

		PRINCIPLES OF UNIVERSAL DESIGN						
		EQUITABLE USE	FLEXIBILITY IN USE	SIMPLE AND INTUITIVE USE	PERCEPTIBLE INFORMATION	TOLERANCE FOR ERROR	LOW PHYSICAL EFFORT	SIZE AND SPACE FOR APPROACH AND USE
KALEHAN ECDAT PARK	PARK ENTRANCES	✓	✓	✓	PARTIALLY	✓	✓	✓
	PARKING AREA	PARTIALLY	PARTIALLY	✓	PARTIALLY	PARTIALLY	PARTIALLY	✓
	PEDESTRIAN PATHWAYS AND CIRCULATION	PARTIALLY	✓	✓	✓	✗	✓	✓
	URBAN EQUIPMENT	PARTIALLY	PARTIALLY	PARTIALLY	✗	PARTIALLY	✓	PARTIALLY
	LANDSCAPE AND WAYFINDING	✗	✗	PARTIALLY	✗	✗	PARTIALLY	PARTIALLY

Olympic Park

Olympic Park is one of the large-scale public open spaces in Konya that combines sports and recreation-focused uses. Approximately 160,000 m²a park of that size, In the early 2010s, It has been opened to the public and is among the city's important green areas. (Figure 12). It is emphasized that large-scale urban parks play a decisive role in promoting physical activity as well as social interaction and quality of life (UN-Habitat, 2020).

Figure 12. Map view of the Olympic Park.

The spatial design of the park emphasizes the integration of sports and social life. Large grassy areas, walking paths, bicycle trails, and outdoor sports areas allow users to engage in physical activity individually or in groups. Such multifunctional open spaces are known to diversify public space use and increase levels of physical activity (WHO, 2016).

The ponds and water channels included in the landscape design enhance the visual appeal of the park and contribute to microclimatic comfort. Studies have shown that water features in public open spaces increase the time users spend in the space and their perceived comfort level (Loukaitou-Sideris et al., 2016). The park also includes children's playgrounds, rest areas, and shaded seating areas. These amenities support recreational diversity, appealing to different age groups (Figure 13).

Figure 13. Aerial view of the Olympic Park.

This scale and spatial diversity make the Olympic Park a suitable study area for evaluating accessibility in line with Universal Design Principles. It also demonstrates that the organization of a large area makes the circulation, wayfinding, and safety components all the more critical.

Park Entrances

The Olympic Park has an entrance layout that allows both vehicular and pedestrian access through two main entry points. The entrance openings, approximately 7 meters wide, allow different user groups to access the park area without barriers, partially supporting the principles of **equitable use** and **low physical effort**. The clear and legible design of the entrances allows users to easily navigate the park area, contributing to the principle of **simple and intuitive use**. However, the directional and informational elements in the entrance areas are not integrated in a visual, tactile, or auditory manner. This indicates that the principles of **perceptible information, flexibility in use,** and **tolerance for error** are met to a limited extent. While the entrance layout of the Olympic Park meets the basic requirements of accessibility, it is partially adequate in terms of universal design principles.

Parking Area

The perimeter of the Olympic Park is supported by parking areas located on both sides, offering a capacity of approximately 350 vehicles. These parking areas are situated approximately 1 meter from the park's access points. This allows users to reach the area within a short distance, partially supporting the principles of **simple and intuitive use and low physical effort**. However, the lack of designated parking spaces for disabled individuals limits accessibility for wheelchair users and those requiring ample maneuvering space. Therefore, this is inconsistent with the principles of **equitable use** and **flexibility in use**.

Additionally, the absence of directional and informational elements for accessible parking spaces reveals that the principle of **perceptible information** is not adequately met. The lack of warning arrangements in parking areas to guide users towards potential risks weakens the principle of **tolerance for error**. The failure to define appropriate dimensions and maneuvering areas for accessing the parking space indicates that the principle of providing **size and space for approach and use** is also only partially met (Figure 14).

Figure 14. Parking areas of Olympic Park

Pedestrian Pathways and Circulation

The walking paths in the Olympic Park are arranged along three separate axes starting from the entrance. The main path is approximately 1030 cm wide, while the side paths are approximately 4 m wide. The designation of 1 m of each side path as a running path and another 1 m as a cycling path allows for different types of movement, supporting the principle of **flexibility in use**. The varying path widths throughout the park, between 4 and 5 m, allow for comfortable pedestrian flow. This situation presents a favorable circulation model in terms of the principles of **equitable use** and **low physical effort**.

Asphalt and tile paving have been used on the road surfaces, and there are no significant elevation differences throughout the park. This contributes to the principle of providing **size and space for approach and use** by ensuring uninterrupted and level circulation. However, the absence of directional signs and guidelines, except for running and cycling paths, makes navigation difficult, especially for visually impaired individuals. This indicates that the principles of **perceptible information** and **simple and intuitive use** are met to a limited extent. In addition, the lack of warning arrangements to inform the user of possible risks along the circulation path reveals that the principle of **tolerance for error** is also only partially met (Figure 15).

Figure 15. Olympic Park walkways and axes.

Urban Equipment (Lighting, Trash Cans, etc.)

Access to the gazebos and picnic areas in the Olympic Park is sometimes via grassy areas due to interruptions in the paved paths. This situation is inconsistent with the principles of **equitable use** and **low physical effort**, as it makes mobility difficult, especially for wheelchair users, elderly individuals, and those using strollers. The discontinuous access routes limit the equal and independent use of these areas by all user groups.

The park features three different types of benches, with seating heights ranging from 40–45 cm. These dimensions provide comfortable seating for many users. However, the fact that most of the benches are located directly in the sun limits physical comfort for extended use (Figure 16). The accessibility of the benches to wheelchairs is a positive feature in terms of **flexibility in use** and the principles of **size and space for approach and use**. However, this makes access to the surrounding placement of some benches difficult and partially weakens the principle of **equitable use**.

Figure 16. Olympic Park seating areas

The park utilizes lighting poles and wall-mounted lights of varying heights (3 m, 12 m, and 16 m), and these elements do not obstruct pedestrian flow (Figure 17). The lighting provides adequate visibility and does not create distracting glare, contributing to users' ability to move safely within the space. This supports the principles of **perceptible information, tolerance for error,** and **simple and intuitive use**.

Figure 17. Olympic Park lighting elements.

Landscape and Wayfinding

The Olympic Park offers recreational diversity with five main sports areas arranged in the shape of the Olympic rings and various thematic gardens (Western, Ottoman, Water, and Japanese Gardens) (Figure 18). A mini soccer field, basketball court, outdoor exercise equipment, children's playgrounds, and cycling and running tracks provide **flexibility in use** for different age groups and usage patterns. However, access to the recreation and sports areas is largely via grass surfaces. This situation is particularly inconsistent with the principles of **equitable use** and **low physical effort** for wheelchair users and individuals with mobility limitations.

The use of glossy and slippery surface materials in some areas, along with the limited number of shading elements, negatively impacts user safety and comfort. This weakens the principle of **tolerance for error**. The fact that the pond in the Japanese Garden is surrounded by railings offers a positive practice in terms of safe use. However, the lack of consistent application of this approach to all water features throughout the park limits the continuity of the **equitable use** principle. The park landscape is predominantly designed based on visual experience, and there are insufficient plants or spatial elements that serve a directional function. This indicates that the principle of **perceptible information** is met to a limited extent.

Figure 18. Olympic Park recreation and sports areas.

The absence of a comprehensive wayfinding map at the park entrance and the insufficient number of directional signs weaken the principle of **simple and intuitive use** for first-time users (Figure 19). The lack of alternative information transfer tools, such as guidelines, tactile surfaces, or auditory guidance on the walkways, reveals that the principle of providing **size and space for approach and use** is not adequately met in terms of accessibility (Figure 20). These findings indicate that while the recreation and sports areas of the Olympic Park offer spatial diversity, they need to be improved in terms of wayfinding and safety in accordance with universal design principles.

Figure 19. Olympic Park directional signs.

Figure 20. Examples of plant landscaping in the Olympic Park

Spatial analyses of the Olympic Park indicate that, thanks to its large scale and sports-focused design, it possesses strong potential for physical activity and recreation. However, aspects such as wayfinding, continuity of circulation, and the unequal accessibility of certain urban amenities for all user groups reveal areas that require improvement within the framework of universal design principles.

Accordingly, the park's entrances, parking areas, pedestrian walkways, urban amenities, landscaping, and wayfinding components were evaluated within the framework of Universal Design Principles, and the findings are presented in Table 2.

Table 2. Evaluation of Olympic Park Design according to Universal Design Principles

		PRINCIPLES OF UNIVERSAL DESIGN						
		EQUITABLE USE	FLEXIBILITY IN USE	SIMPLE AND INTUITIVE USE	PERCEPTIBLE INFORMATION	TOLERANCE FOR ERROR	LOW PHYSICAL EFFORT	SIZE AND SPACE FOR APPROACH AND USE
OLİMPİYAT PARK	PARK ENTRANCES	✓	✓	✓	PARTIALLY	✓	✓	✓
	PARKING AREA	✗	✗	PARTIALLY	✗	✗	✗	PARTIALLY
	PEDESTRIAN PATHWAYS AND CIRCULATION	PARTIALLY	✓	PARTIALLY	✗	PARTIALLY	✓	✓
	URBAN EQUIPMENT	PARTIALLY	PARTIALLY	PARTIALLY	PARTIALLY	✓	PARTIALLY	PARTIALLY
	LANDSCAPE AND WAYFINDING	✗	PARTIALLY	PARTIALLY	✗	PARTIALLY	✗	PARTIALLY

80 Binde Devr-i Alem Park

80 Binde Devr-i Alem Park is a significant urban space in Konya that stands out among culturally themed public open spaces with its unique content and scale. Planned by Meram Municipality, the park opened in 2014 and, with its area of approximately 80,000 m², is among the large-scale thematic parks in the city (Figure 21).

Figure 21. Map view of the 80 Binde Devr-i Alem Park.

The park's spatial design is based on the open-air representation of selected periods of Turkish and world history through historical figures, miniature structures, and thematic sculptures. In this respect, the park differs from classical recreation areas and has the character of a public space focused on learning, discovery, and experience (Figure 22). Theme parks are seen as offering educational potential, especially for children and young people, and supporting cultural awareness.

Figure 22. 80 Binde Devr-i Alem Park.

A holistic circulation system has been created between the thematic sections designed over a large area; wide lawn surfaces, pedestrian paths, and the continuity of open spaces have been decisive in the spatial organization of the park. The ponds and water channels located within the park are among the important aesthetic and microclimatic components of the landscape design; they support the comfort of the open space (Gehl & Svarre, 2013; WHO, 2016).

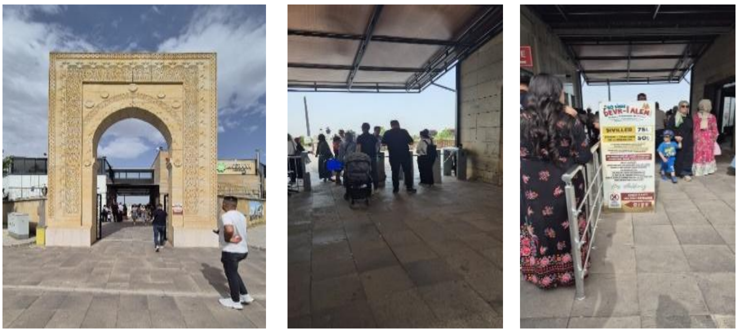
The park, heavily used by families, children, and tourists visiting the city, is not only a local recreational area but also a public open space that represents the city's identity and supports cultural tourism (Aylan & Şalvarcı, 2018). These characteristics make the 80 Binde Devr-i Alem Park a suitable and meaningful study area for evaluating its accessibility in accordance with Universal Design Principles.

Park Entrances

Because the park has a toll entrance system, there is only one main entrance gate. Providing free entry to disabled and elderly individuals is a positive practice supporting the principle of **equitable use.** However, long queues form at the ticket booths and turnstiles during peak times, and there are no shaded areas in the waiting zones. This situation is particularly incompatible with the principles of **low physical effort, flexibility in use,** and **tolerance**

for error, especially for disabled and elderly individuals. The presence of separate passage areas for wheelchairs and strollers at the turnstiles supports the principles of simple and **intuitive use** by providing an appropriate size and space. The approximately 5 m wide ramp with a 7% incline, located after the entrance, provides an accessible connection to the park's internal circulation. This situation has been evaluated as a positive arrangement in terms of **low physical effort, size and space for approach and use**, and **equitable use** principles (Figure 23).

Figure 23. Entrance gate and turnstiles of 80 Binde Devr-i Âlem Park.



Parking Area

Vehicles are not allowed to enter the parking area. Visitors use a parking lot located near the entrance with a capacity of approximately 600 vehicles. The quantitatively sufficient parking capacity supports the principle of **simple and intuitive use**, as it can accommodate the high user density. However, the presence of only 4 disabled parking spaces constitutes a significant limitation in terms of accessibility, considering the high usage rate. This situation is inconsistent with the principles of **equitable use** and **flexibility in use**. The 400 cm width of the disabled parking spaces contributes to the principle of providing **size and space for approach and use** for maneuvering.

The fact that the distance between the parking lot and the parking entrance varies between 5–30 m increases the physical exertion requirement, especially for individuals with mobility limitations. This indicates that the principle of **low physical effort** is only partially met. The limited guidance from the parking lot to the parking entrance weakens the principle of **perceptible information**, while the lack of user support measures reveals that the principle of **tolerance for error** is also only partially fulfilled (Figure 24).

Figure 24. Parking area of 80 Binde Devr-i Alem Park.

Pedestrian Pathways and Circulation

The park consists of three thematic sections. An outline drawing showing the entire area at the entrance allows users to perceive the space in general terms, supporting the principles of **perceptible information and simple and intuitive use**. The main axis, designed with a width of 4–5 meters, provides a circulation infrastructure capable of handling high visitor flow. This is a positive aspect in terms of **equitable use** and **low physical effort**. However, the side paths have narrow widths ranging from 120–200 cm. This makes passage difficult, especially during peak usage periods, and limits the simultaneous movement of different user groups.

Figure 25. Main and secondary axes of 80 Binde Devr-i Alem Park.

Seating elements located in narrow passageways reduce accessibility for wheelchair users by restricting maneuvering space. This is inconsistent with the principles of **size and space for approach and use** provision, as well as **flexibility in use**. The tile and flat surface provide uninterrupted circulation. However, the high usage and narrow passages require users to exert more physical effort. This highlights an area for improvement in terms of **low physical effort** and **equitable use** principles.

Ramps and stairs connect different levels of the park. The stairs, with a riser height of 18 cm and a width of approximately 2 m, offer a positive measure in terms of safe passage. However, the fact that some ramps are only 1 m wide and lack handrails severely limits accessibility. In addition, some ramps have a slope exceeding 7%, the ramp-stair combination is inappropriately positioned, and there is insufficient maneuvering space at corners. This situation poses a risk, especially for wheelchair users, and shows that the **tolerance for error** principle is not adequately met (Figure 26).

Figure 26. Stairs and ramps of the 80 Binde Devr-i Alem Park.

Urban Equipment (Lighting, Trash Cans, etc.)

The resting areas feature two different types of benches, with seating heights of approximately 45 cm. While wheelchair access to the benches is only partially possible, this offers limited advantages in terms of **flexibility in use** and **size and space for approach and use**. However, the seating areas largely lack shade. This reduces physical comfort, particularly for elderly individuals and those using the benches for extended periods, weakening the principle of **low physical effort**.

The water features (ornamental pools and ponds) throughout the park are not adequately supported by protective measures. The fact that a child was at risk of falling into the pool during the observation indicates that the principles of **equitable use** and **tolerance for error** are not adequately met in these areas. The lighting elements are positioned at approximately 320 cm height and do not obstruct pedestrian movement. This presents a positive arrangement in terms of **equitable use** and **simple and intuitive use**. However, the limited duration of lighting use is due to the park being closed to nighttime use. This partially limits the impact of lighting on accessibility (Figure 27).

Figure 27. Benches in the 80 Binde Devr-i Alem Park.

Landscape and Wayfinding

The park has a children's playground with a non-slip surface and easy access (Figure 28). These features demonstrate that the playground is fundamentally accessible in terms of **equitable use, simple and intuitive use**, and **low physical effort**. However, the absence of shade elements reduces physical comfort, especially during prolonged use in the summer months. This particularly limits the principle of **flexibility in use**.

Figure 28. Playgrounds of 80 Binde Devr-i Alem Park

Although the park features fragrant plants and various landscaping elements, these elements do not serve a directional function. The landscaping is primarily based on visual impact. Some tree branches hanging over the walkways make passage difficult, highlighting the need for maintenance and adjustments to ensure **size and space for approach and use**, as well as **equitable use**. While directional signs are present in the park, Braille, tactile surfaces, or audio information systems are absent. This indicates that the principles of **perceptible information** and **tolerance for error** are only partially met, particularly for visually impaired individuals (Figure 29).

Figure 29. Direction signs for the 80 Binde Devr-i Alem Park.

Spatial analyses of the 80 Binde Devr-i Alem Park show that it offers a powerful experience with its thematic design and large scale. However, it was concluded that accessibility is not comprehensively ensured in terms of entrance layout, pedestrian circulation, ramps, urban amenities, and wayfinding systems.

Accordingly, the park's entrances, parking areas, pedestrian walkways, urban amenities, landscaping, and wayfinding components were evaluated within the framework of Universal Design Principles, and the findings are presented in Table 3.

Table 3. Evaluation of 80 Binde Devr-i Alem Park according to Universal Design Principles

		PRINCIPLES OF UNIVERSAL DESIGN						
		EQUITABLE USE	FLEXIBILITY IN USE	SIMPLE AND INTUITIVE USE	PERCEPTIBLE INFORMATION	TOLERANCE FOR ERROR	LOW PHYSICAL EFFORT	SIZE AND SPACE FOR APPROACH AND USE
80 BİNDE DEVR-İ ALEM PARK	PARK ENTRANCES	PARTIALLY	PARTIALLY	PARTIALLY	PARTIALLY	✗	PARTIALLY	PARTIALLY
	PARKING AREA	PARTIALLY	✗	PARTIALLY	✗	✗	PARTIALLY	PARTIALLY
	PEDESTRIAN PATHWAYS AND CIRCULATION	✗	✗	✗	PARTIALLY	✗	✗	✗
	URBAN EQUIPMENT	✗	✗	PARTIALLY	✗	✗	✗	✗
	LANDSCAPE AND WAYFINDING	✗	✗	PARTIALLY	✗	✗	✗	✗

EVALUATION OF FINDINGS

As a result of the analyses, Kalehan Ecdat Park, Olympic Park, and 80 Binde Devr-i Alem Park were comparatively evaluated within the scope of criteria determined in line with universal design principles. The evaluation process considered equitable use, flexibility in use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and size and space for approach and use.

This analysis was not limited to physical accessibility criteria alone, but also considered how users experience the space, the impact of spatial elements on safety and comfort, and the inclusive use potential of the parks. Thus, the strengths and weaknesses of each park were evaluated within a multidimensional accessibility perspective. Walking paths, ramps, stairs, directional elements, seating areas, recreation areas, and landscape arrangements were examined separately within the context of Universal Design Principles. The findings are presented comparatively in Table 4.

Table 4. Comparative Evaluation of the Examined Parks according to Universal Design Principles

PRINCIPLES OF UNIVERSAL DESIGN		EQUITABLE USE	FLEXIBILITY IN USE	SIMPLE AND INTUITIVE USE	PERCEPTIBLE INFORMATION	TOLERANCE FOR ERROR	LOW PHYSICAL EFFORT	SIZE AND SPACE FOR APPROACH AND USE
KALEHAN ECDAT PARK	PARK ENTRANCES	✓	✓	✓	PARTIALLY	✓	✓	✓
	PARKING AREA	PARTIALLY	PARTIALLY	✓	PARTIALLY	PARTIALLY	PARTIALLY	✓
	PEDESTRIAN PATHWAYS AND CIRCULATION	PARTIALLY	✓	✓	✓	✗	✓	✓
	URBAN EQUIPMENT	PARTIALLY	PARTIALLY	PARTIALLY	✗	PARTIALLY	✓	PARTIALLY
	LANDSCAPE AND WAYFINDING	✗	✗	PARTIALLY	✗	✗	PARTIALLY	PARTIALLY
OLİMPİYAT PARK	PARK ENTRANCES	✓	✓	✓	PARTIALLY	✓	✓	✓
	PARKING AREA	✗	✗	PARTIALLY	✗	✗	✗	PARTIALLY
	PEDESTRIAN PATHWAYS AND CIRCULATION	PARTIALLY	✓	PARTIALLY	✗	PARTIALLY	✓	✓
	URBAN EQUIPMENT	PARTIALLY	PARTIALLY	PARTIALLY	PARTIALLY	✓	PARTIALLY	PARTIALLY
	LANDSCAPE AND WAYFINDING	✗	PARTIALLY	PARTIALLY	✗	PARTIALLY	✗	PARTIALLY
80 BİNDE DEVR-İ ALEM PARK	PARK ENTRANCES	PARTIALLY	PARTIALLY	PARTIALLY	PARTIALLY	✗	PARTIALLY	PARTIALLY
	PARKING AREA	PARTIALLY	✗	PARTIALLY	✗	✗	PARTIALLY	PARTIALLY
	PEDESTRIAN PATHWAYS AND CIRCULATION	✗	✗	✗	PARTIALLY	✗	✗	✗
	URBAN EQUIPMENT	✗	✗	PARTIALLY	✗	✗	✗	✗
	LANDSCAPE AND WAYFINDING	✗	✗	PARTIALLY	✗	✗	✗	✗

The comparative evaluation results presented in Table 4 reveal that the parks exhibit varying levels of performance in terms of universal design principles. The findings demonstrate that spatial components, ranging from park entrances and circulation systems to urban amenities, landscaping, and wayfinding elements, play a decisive role in accessibility and inclusivity. Accordingly, the accessibility performance of the parks is discussed in detail below.

In terms of park entrances, Kalehan Ecdat Park stands out as the most accessible park with its wide, level, and intuitively understandable entrance layout. In the Olympic Park, the integration of vehicle and pedestrian entrances in the same area makes wayfinding somewhat difficult and limits the accessibility of the entrance experience. In contrast, the single entrance, ticket booth, and turnstile system in the 80 Binde Devr-i Alem Park leads to long waits during peak times, significantly reducing accessibility, especially for disabled and elderly individuals. In this context, the entrance layouts of the parks clearly differ in terms of simple and intuitive use, and flexibility in use principles.

When parking areas are examined, Kalehan Ecdat Park and Olympic Park, while having sufficient capacity, exhibit a partially accessible structure due to the limited or insufficiently defined parking spaces reserved for disabled users. In 80 Binde Devr-i Alem Park, the inadequacy of the number of disabled parking spaces relative to the park's usage intensity makes it the weakest park in terms of accessibility. Considering the distance of the parking lots from the park entrances and the continuity of barrier-free access, it is seen that the principles of equitable use and low physical effort are met to varying degrees among the parks.

In terms of pedestrian walkways and circulatory systems Kalehan Ecdat Park is considered to be the park that best supports barrier-free and independent movement thanks to its wide and uninterrupted pedestrian axes. While the main circulation axes in the Olympic Park are sufficiently wide, access to gazebos and resting areas via grassy surfaces partially weakens the continuity of circulation. In the 80 Binde Devr-i Alem Park, the narrowing of pedestrian paths, the obstruction of passages by equipment, and insufficient maneuvering areas particularly hinder wheelchair users. This severely restricts independent movement. This creates a significant divergence in terms of the principles of unimpeded movement between parks and low physical effort.

In terms of urban equipment, Kalehan Ecdat Park and Olympic Park meet basic accessibility requirements in terms of benches, lighting elements, and resting areas, but exhibit only partially adequate performance in terms of providing equal accessibility to all user groups through shading and amenities. In the 80 Binde Devr-i Alem Park, however, the placement of amenities, lack of shading, and insufficient safety measures around water features weaken the principles of equitable use and tolerance for error. This situation poses a risk, particularly for children and users with limited mobility.

Landscaping and wayfinding, under this heading, Kalehan Ecdat Park and Olympic Park offer a more legible and safe spatial structure thanks to the fact that the plant arrangements do not obstruct pedestrian movement. In contrast, in the 80 Binde Devr-i Alem Park, the encroachment of plant elements onto pedestrian paths, the irregular landscape design, and inadequate safety measures around the water areas limit unimpeded movement and safe use. Although all three parks have visual directional signs, the absence of tactile surfaces, audio guidance systems, and elements supporting multisensory information transfer indicates that the principle of perceptible information is generally weak.

Conclusion and Recommendations

In this study, Kalehan Ecdat Park, Olympic Park, and 80 Binde Devr-i Alem Park in Konya were comparatively evaluated in accordance with Universal Design Principles. The findings indicate that accessibility in urban parks cannot be explained by singular physical arrangements; rather, continuity of circulation, spatial legibility, multisensory information, safety, and usability are crucial factors. It shows that comfort can be enhanced through a holistic approach that considers all aspects of life.

According to the comparative results, Kalehan Ecdat Park stands out as the most balanced park, exhibiting a more consistent accessibility profile in terms of entrance-circulation relations and overall spatial continuity. Olympic Park offers significant potential for public use with its scale and sports-focused design; however, this potential is not integrated with universal design components at the same level. 80 Binde Devr-i Alem Park, despite its strong thematic identity, reveals that the components determining the accessibility experience (entrance management, interconnections, security, and wayfinding) become more decisive under conditions of high usage.

In this context, the study, using the Konya example, provides a practical evaluation framework demonstrating which spatial components can be used to interpret park accessibility and which criteria can be used to produce comparisons between parks. Thus, a framework has been established that can contribute to the production of comparable data, the development of criteria, and methodological continuity for research to be conducted in different cities and different park types.

Accordingly, based on the evaluation findings, the following suggestions are presented for strengthening accessibility in city parks in Konya.

- Park entrances should be at least 3 meters wide and designed to be accessible to people with disabilities and capable of accommodating high-volume use.
- Entrance areas should include shaded waiting areas, seating elements, and legible directional signs.
- The slope of entrance ramps should not exceed 7%, and ramps must have double-sided handrails and grab bars.
- Parking spaces reserved for disabled users should be at least 3.60 m wide and located as close to entrances as possible.
- The number of disabled parking spaces should be increased in accordance with the usage intensity of the park.

- Seamless, paved, and barrier-free access routes should be created from the parking lot to the parking area.
- Pedestrian walkways should be designed with non-slip, smooth, and continuous surfaces, at least 1.50 m wide.
- Pedestrian and bicycle paths should be clearly separated by different textures, colors, or elevation differences.
- In areas with elevation differences, ramps and stairs should be arranged together to create a safe and intuitive circulation system.
- The park should include shaded seating and resting areas at approximately 30-meter intervals.
- Sufficient maneuvering space should be left around the chair and the benches for wheeled vehicles to approach.
- Camellias and picnic areas should be provided with hard-surfaced, uninterrupted, and barrier-free access.
- Landscape elements should be positioned in a way that does not restrict circulation and facilitates wayfinding.
- Water features such as ponds and ornamental pools should be surrounded by permanent and robust safety barriers.
- Direction and information systems should be supported by Braille, tactile surfaces, and audio systems where necessary; tactile maps should be placed at entrances.

In this respect, the study supports the existing literature on the applicability of universal design principles in open spaces; it presents an evaluative approach that can serve as a reference for future research across different cities, park types, and user profiles. Integrating these recommendations into municipalities' design, implementation, and maintenance processes will help make parks more inclusive for all users.

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CHAPTER 6

POST-OCCUPANCY EVALUATION OF HYBRID EDUCATIONAL BUILDINGS: A THERMAL AND VISUAL COMFORT ANALYSIS

ZEHRA NUR DISCI[1]

Introduction

Indoor environmental conditions represent a critical issue that significantly affects people’s productivity and mental acuity (Bakó-Biró et al., 2012; de Dear, 2004; Fadeyi, 2014; Fantozzi et al., 2021; Fisk, 2000; Jindal, 2019; Mendell & Heath, 2005; van Hoof, 2008; Wargocki & Wyon, 2007). In the context of educational buildings, comfort conditions require careful consideration as they directly influence students’ learning performance (Wang et al., 2018; Wong & Khoo, 2003). Research indicates that students' performance varies depending on indoor temperature (Wang et al., 2018), and adjusting the temperature can significantly affect the speed at which they complete schoolwork (Wargocki et al., 2019).

Historically, educational buildings have been examined in two groups according to their functions: formal learning spaces and informal study spaces (Oblinger, 2006; Disci, 2025). Formal

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learning spaces, such as classrooms and lecture theatres, are environments designed to support instructor-led learning (Johnson & Majewska, 2022). In these areas, fixed seating arrangements and centralized temperature control systems are generally used to encourage order and minimize distractions (Barrett et al., 2015; Jamieson et al., 2000). Conversely, informal study spaces provide students with adaptable, unstructured environments for studying, collaborating, and socializing (Hunter & Cox, 2014; Disci et al., 2025). While student lounges and cafeterias serve this purpose, the most prominent example is the university library (Anggiani & Heryanto, 2018; Lomas & Oblinger, 2006). Modern libraries have evolved beyond simple book repositories; they now include other functions such as computer rooms, lecture rooms, and group study areas (Altan, 2010). These spaces often offer quiet areas, collaborative desks, and comfortable seating that accommodate a variety of study preferences (Beagle, 1999). This flexibility grants students the freedom to choose an environment that meets their specific needs (Hunter & Cox, 2014; Montgomery & Miller, 2011), allowing for a more personalized experience and the ability to adapt to changing environmental conditions (Hunter & Cox, 2014).

However, ensuring comfort in these multi-functional buildings is complex. Newly constructed higher education buildings increasingly rely on automated environmental control systems due to advances in technology. Although these systems were expected to reduce energy use, existing studies have found that results often do not meet expectations (Lawrence et al. 2019). Furthermore, there is a distinct relationship between energy consumption and comfort; for instance, the Carbon Trust (2007) report underscores the detrimental impact of overheating on fuel consumption, while even a 1°C decrease in indoor temperature can provide significant energy savings (Nicol et al., 2012). This creates a challenge in defining comfort standards. CIBSE Guide A: Environmental Design provides guidance on these aspects, specifying ideal temperature values for different spaces (CIBSE Guide A, 2015; Nicol et al., 2012). As summarised in Table 1, educational buildings and computer rooms share the same comfort criteria (19-21°C in winter), whereas library reading rooms have different criteria (22-23°C in winter) (CIBSE Guide A, 2015). For hybrid buildings like the Information Commons (IC), which function simultaneously as libraries and computer clusters, the sub-categorisation of reading rooms under 'library' in CIBSE Guide A may not be adequate, as these areas are now used for many different functions (Altan, 2010).

Table 1: Recommended comfort criteria for specific applications.

Type of building/ space	Customary *winter* conditions			Customary *summer* conditions			Maintained illuminance / (lux)
	Temp. (°C)	Activity (met)	Clothing (Clo)	Temp. (°C)	Activity (met)	Clothing (clo)	
Computer Rooms	19-21	1.4	1.0	21-25	1.3	0.6	300
Educational Buildings Lecture halls	19-21	1.4	1.0	21-25	1.3	0.6	500
Libraries: Reading rooms	22-23	1.1	1.0	24-25	1.1	0.6	500

Source: CIBSE Guide A, 2015.

Understanding the user profile is also essential. Unlike occupants in residential buildings who have the freedom to adjust their environment and clothing to achieve personal thermal comfort (de Dear et al., 2018; Rijal et al., 2013), students in educational buildings often have limited scope to adapt (Wong & Khoo, 2003). Similar to office environments where energy costs are covered by the employer (Strengers, 2010), students do not pay the bills themselves and may prefer using air conditioning over adaptive behaviours (Zaki et al. 2017). Therefore, finding the discrepancies between design standards and user experience in these 24-hour hybrid spaces is crucial for future sustainable design. In parallel with thermal challenges, the quality of indoor lighting is a fundamental determinant of occupant comfort, well-being, and productivity (Al Horr et al., 2016). However, evaluating lighting quality solely through photometric measurements is often insufficient, as it does not capture the full user experience (Allan et al., 2019). Consequently, current research emphasises the necessity of considering user feeling alongside physical measurements, an aspect that has historically been overlooked (CIE 213, 2014; Dubois et al., 2016).

In educational contexts, exposure to daylight is strongly linked to enhanced cognitive performance (Shishegar & Boubekri, 2016; Jamrozik et al., 2019). Furthermore, students' satisfaction with visual conditions is associated with their mood, behaviour, and academic outcomes (Wang & Boubekri, 2011; Sakellaris et al., 2016). Beyond comfort, aligning lighting strategies with occupant expectations offers significant sustainability benefits; for instance, Yun et al. (2012) showed that adjusting indoor lighting based on user needs can reduce energy consumption by up to 43%. Furthermore, daylight availability plays a pivotal role in how students interact with library spaces. Research shows that daylight is often the most dominant factor influencing seat selection in libraries, taking precedence over other environmental parameters such as privacy, outdoor views, and quietness (Izmir Tunahan et al., 2022). However, a significant discrepancy often exists between photometric data and user experience; studies using the daylight boundary line method have shown that perceived daylight conditions vary extensively from person to person, regardless of the actual measurements (Izmir Tunahan et al., 2022). This highlights the importance of understanding the subjective "human factor" alongside objective data to explain why occupants may feel dissatisfied even when standard light levels are met.

According to CIBSE guidelines, the fundamental aim of energy-efficient lighting is to align the illuminance levels with the specific requirements of the task. Since activities within a space may change over time, providing user-adjustable lighting is highlighted as a critical strategy. This approach yields a dual benefit: it enhances user satisfaction by offering control over the environment and prevents energy wastage by avoiding over-illumination. Lighting design serves three primary purposes: ensuring occupant safety, helping exact task execution, and creating a pleasing visual aesthetic. While a functional environment can be achieved through electric lighting alone, there is a strong occupant preference for daylight. CIBSE emphasises that effective design should harness daylight not only to save energy but also to improve the internal atmosphere if issues such as glare and overheating are mitigated. A successful lighting strategy must strike a balance between the rigorous demands of performance and the creation of a pleasant, inspiring atmosphere proper to the building's operational context (CIBSE Guide A, 2015).

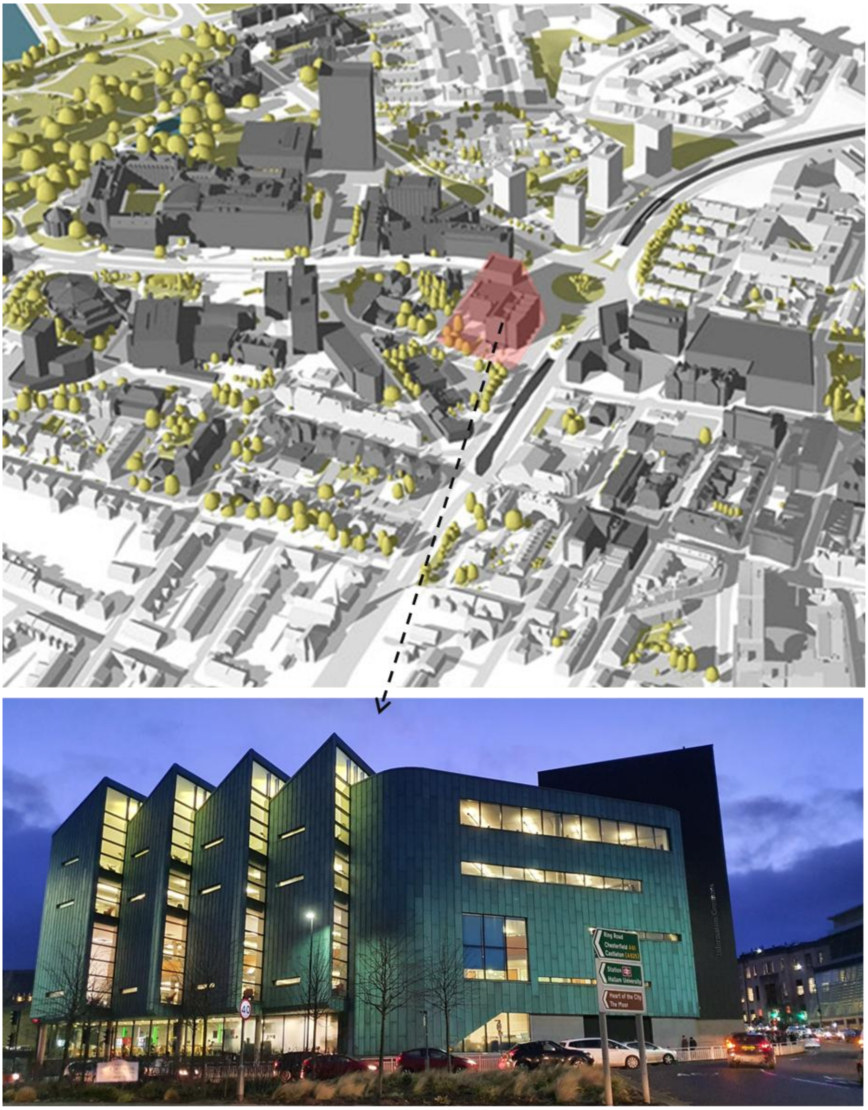
To explore these theoretical conflicts in a real-world setting, this chapter presents a post-occupancy evaluation of the University of Sheffield's Information Commons (IC). By analysing spot measurements of thermal and visual conditions alongside observational data, this study investigates the intersection of sustainable design strategies and user experience in a continuously operating facility. The following sections will critically examine how the building's physical performance aligns with established standards and where it diverges due to the complex nature of 24-hour usage.

Case Study Description: The Information Commons

For this study, the Information Centre (IC) at the University of Sheffield was chosen as a prime example of a modern and technologically advanced educational facility. Opened in 2007, the building is a seven-story structure with a total area of approximately 11,500 m^2. It operates 24/7 to meet the demanding study habits of the student population. Unlike traditional libraries, the IC is designed as a hybrid learning environment integrating acoustic privacy zones ranging from extensive computer clusters, group study rooms, and social interaction areas to quiet study spaces.

In terms of sustainability, the building incorporates various design strategies aimed at supporting user comfort while minimizing its environmental footprint. The main objective of these strategies is to ensure user comfort. Key features of the building include a greywater harvesting system that filters rainwater for sanitary use and a high-performance thermal insulation system designed to prevent heat loss. In addition, it uses air conditioning modules to provide thermal comfort. As shown in Figure 1, the building is located near a busy tram line and vehicle traffic, therefore it has used special acoustic insulation on the facade to reduce external noise ingress. It also has a north-facing orientation to maximize natural light while preventing glare.

Figure 1. Site context and exterior overview of the Information.



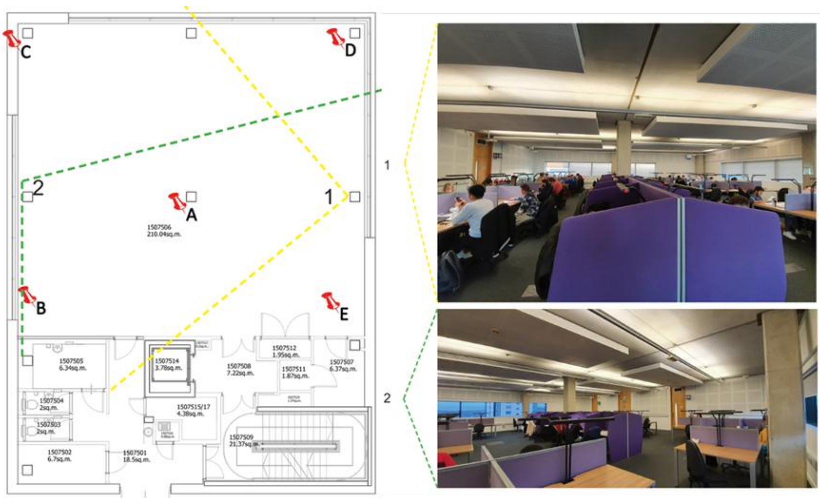
Source: Grant Associates & Feilden Clegg Bradley Studios

To assess whether these design strategies were working effectively, a post-occupancy evaluation was conducted using environmental measurement and thermal imaging devices. The study was designed to capture the performance difference during different operational phases of the building. Therefore, measurements were taken in two contrasting periods. These included two measurements: one at 3 PM to represent peak daylight use and another at midnight to analyse the building's performance in 24-hour operating mode.

Data collection was conducted on 23 and 24 January 2020. On these dates, outdoor temperatures were recorded as 10°C in the afternoon and 7°C at midnight. This represents typical UK winter conditions. For comparative analysis, two specific zones with different functional requirements were selected. The first zone is the 4th Floor General Study Area, a flexible space with bookshelves and group study rooms, providing a collaborative and informal learning environment. The measurement points (A, B, C) for this zone are shown in detail in Figure 2. The second area is the Quiet Room on the 5th floor, designed for focused individual work, with measurement points (A-E) shown in Figure 3. One of the most significant differences between the two areas is that the 4th floor has a larger open workspace, while the 5th floor is a smaller, enclosed space. In both areas, quantitative data on air temperature and lighting levels were recorded using a multifunctional environmental measuring device at designated points to ensure spatial coverage. In addition, thermal imaging was used to find thermal bridges and evaluate the effectiveness of insulation under real-time conditions.

Figure 2. Floor plan of the 4th Floor General Study Area showing measurement points (A, B, C).

Figure 3. Floor plan of the 5th Floor Silent Room showing measurement points (A-E).



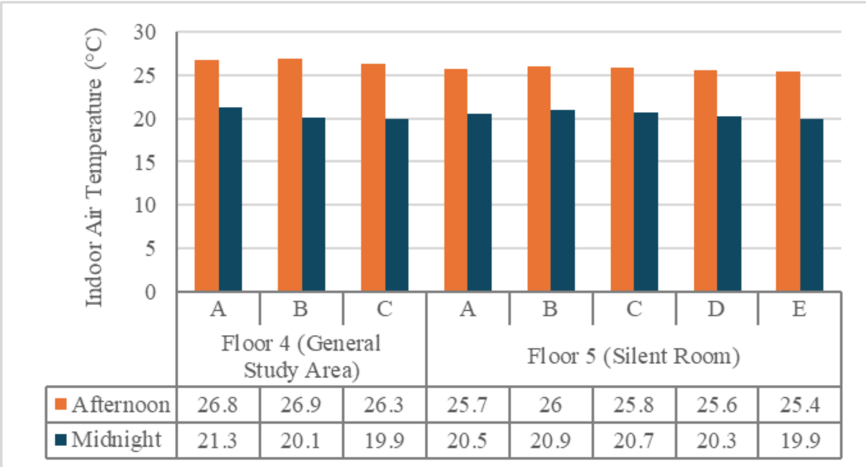
Post-Occupancy Evaluation

To evaluate the indoor comfort conditions of the IC building, which is used by students 24 hours a day, environmental data measurements were taken at specific points on the 4th and 5th floors of the building. The data obtained from these measurements are analysed in this section under two headings: Thermal Performance and the "Comfort Gap" and Visual Comfort and Illuminance Levels.

Thermal Performance and the "Comfort Gap"

Thermal measurements showed that the building effectively retained heat during the day but experienced a significant drop in temperature at night. Figure 4 shows that in the afternoon measurement, with an outside temperature of approximately 10°C, the indoor temperatures on the 4th floor (General Study Area) averaged between 26.3°C and 26.9°C. Similarly, temperatures on the 5th floor (Silent Room) ranged from 25.4°C to 26°C. These values are significantly higher than the CIBSE Guide A recommendation of 22-23°C for winter operating temperatures in library reading rooms. This is likely due to high student density and internal heat gains from computer equipment. It also highlights a potential overheating problem during peak usage hours. However, midnight measurements presented a different challenge. When the outside temperature dropped to 7°C, the indoor temperatures decreased to an average of 20°C to 21°C on both floors. Although these values technically fall within the CIBSE acceptable range for "computer rooms" (19-21°C), subjective observations during the site visit contradicted the instrument data. While the ambient temperature measuring device showed values around 20-21°C, the perceived temperature was significantly lower. It is possible that the lower user density at night, in contrast to the situation during the day, is the reason for this discrepancy.

Figure 4. Comparative temperature readings (°C) for afternoon and midnight measurements on 4th and 5th floors.



	Floor 4 (General Study Area) A	Floor 4 (General Study Area) B	Floor 4 (General Study Area) C	Floor 5 (Silent Room) A	Floor 5 (Silent Room) B	Floor 5 (Silent Room) C	Floor 5 (Silent Room) D	Floor 5 (Silent Room) E
Afternoon	26.8	26.9	26.3	25.7	26	25.8	25.6	25.4
Midnight	21.3	20.1	19.9	20.5	20.9	20.7	20.3	19.9

This discrepancy highlights the challenge of ensuring thermal comfort in 24-hour workspaces. It was observed that "measured" comfort did not match "perceived" comfort. Several factors may contribute to this difference. Firstly, the decreased metabolic rate of students sitting motionless for long periods overnight reduces their body heat production. Secondly, although thermal imaging analysis (Figures 5 and 6) did not show any significant insulation defects, the psychological impact of the dark and cold outside environment visible through large glass facades may be affecting thermal perception. This supports the literature argument that physical measurements alone are insufficient to predict true user satisfaction in hybrid learning spaces.

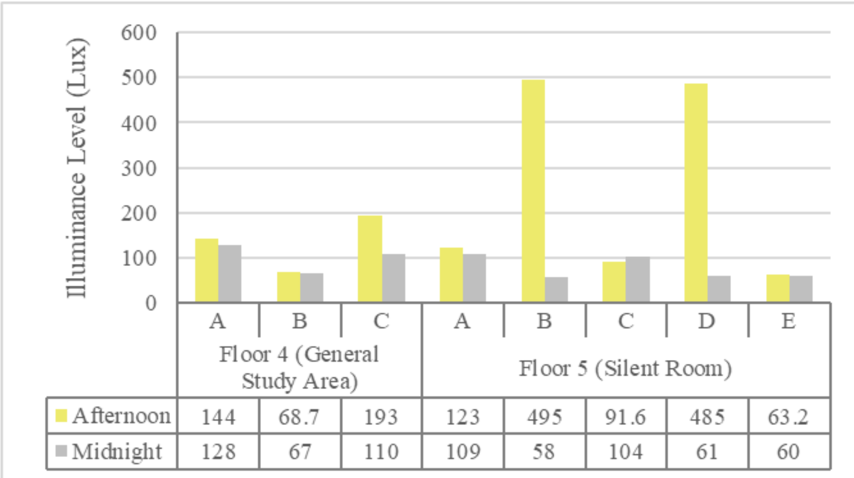
Figure 5. Thermal imaging (FLIR) of the 4th Floor General Study Area showing surface temperature distribution.

Figure 6. Thermal imaging (FLIR) of the 5th Floor Silent Room showing surface temperature distribution.

Visual Comfort and Illuminance Levels

In educational buildings that are actively used 24 hours a day, artificial lighting systems play a significant role in providing visual comfort. Of course, the need for artificial systems varies depending on the time of day. According to CIBSE guidelines, library reading rooms require 500 lux, and computer rooms require 300 lux of maintained illumination. However, this is debatable in buildings that combine both functions. Figure 7 shows the recorded illumination levels in different areas, demonstrating that the building struggles to meet these targets equally across all areas. In the afternoon, areas near the facade (Points B and D on the 5th floor) benefited from daylight, reaching levels of 495 lux and 485 lux respectively. However, the entirely interior areas fell significantly short of these targets; for example, only 63.2 lux was recorded at Point E. The situation worsened considerably at night. During the midnight session, the illumination levels across the 5th floor showed a significant decrease. Previously well-lit peripheral areas (Points B and D) dropped to approximately 58 lux and 61 lux, respectively. These values are critically low for reading activities and do not even meet the recommended lower threshold of 300 lux for computer-based work.

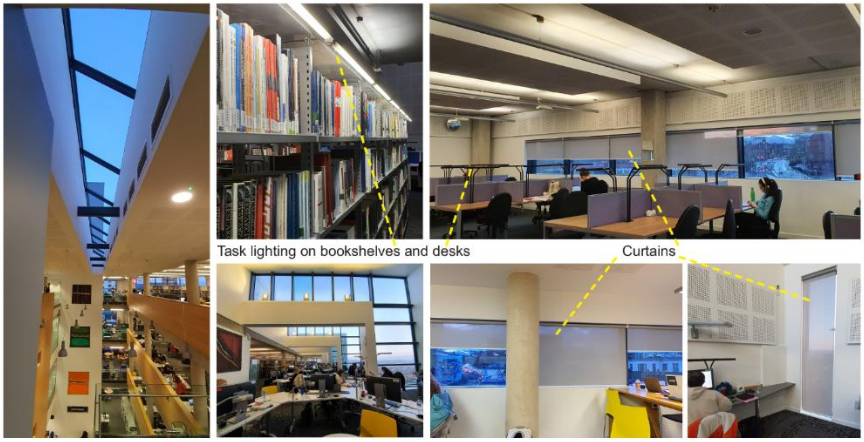
Figure 7. Illuminance levels (Lux) measured on the 4th and 5th floors during afternoon and midnight sessions.



	Floor 4 (General Study Area)			Floor 5 (Silent Room)				
	A	B	C	A	B	C	D	E
Afternoon	144	68.7	193	123	495	91.6	485	63.2
Midnight	128	67	110	109	58	104	61	60

The choice of interior materials is also one of the factors affecting this low performance. As seen in Figure 8, it can be said that the dark-coloured floor materials absorb a significant amount of light instead of reflecting it. This design choice reduces the overall effectiveness of the artificial lighting system. As a result, it was observed that students largely needed individual task lighting (desk lamps) to compensate for the inadequate background lighting. Another striking issue was that the curtains were closed even at midnight. The main reason for this may be that users do not want to bother opening the curtains again after closing them during the day, but it was seen that this situation further increased the feeling of darkness in the environment. Overall, these results contribute to the validation of the CIBSE principle that user control increases satisfaction, but they also reveal a fundamental deficiency in the building's overall lighting strategy for nighttime use.

Figure 8. Interior lighting conditions.



Conclusion

Although the post-occupancy assessment (POE) of the Information Commons building at the University of Sheffield was conducted using short-term measurements, it highlighted the challenges of maintaining optimal indoor environmental quality in a 24-hour hybrid learning environment. Despite the building's strong sustainability strategies, such as acoustic buffering and greywater recovery, the study revealed a significant performance gap between the design intent and the operational reality experienced by students, particularly outside of standard working hours.

The results of the visual comfort analysis showed that architectural choices can impact environmental performance. Measurements showed that the use of dark-coloured coatings, particularly on floors, resulted in light absorption. Since overall illumination levels fell significantly below the recommended standards for study areas, this created a reliance on supplementary task lighting (desk lamps, etc.) during the night. While energy calculations were not performed in this study, it is possible to say that this situation will lead to significant energy losses for a building in active use 24 hours a day. In structures like these, integrating material choice with lighting strategies is crucial to ensure energy efficiency and visual comfort.

Furthermore, thermal evaluation revealed a critical discrepancy between quantitative measurements and qualitative user experience. While temperatures recorded during the midnight session remained within the technically acceptable range of 19-21°C, the subjective perception of the environment was described as significantly colder. This shows that relying solely on instrument measurements is insufficient to assess true comfort in areas where students remain immobile for extended periods overnight. The psychological impact of the cold exterior views visible through the glass facade, combined with the decreased metabolic rates at night, may have contributed to this feeling.

In conclusion, the Information Commons, a multi-functional building that is more than just a library, serves as a valuable case study for future educational building designs. This study shows that meeting regulatory standards such as CIBSE guidelines is not the goal, but merely a minimum requirement. To bridge the gap between physical performance and user satisfaction, future designs for 24-hour learning environments should adopt a more comprehensive approach. This approach should include considering the psycho-physiological needs of nighttime users and ensuring that aesthetic decisions, such as interior finishes, actively support rather than contradict the environmental strategy.

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CHAPTER 7

SPECULATIVE SPACE: THE INTERSECTIONS OF AI, CINEMA AND ARCHITECTURE

FATMA BETÜL KÜNYELİ[1]

Introduction

In the last twenty years, architecture has evolved beyond the design of the physical environment, becoming a hybrid intellectual field intertwined with digital culture, image production technologies, and computational systems. Highlighting the data-driven orientation of digital design, Carpo (2017) states that not only the representational tools of architecture but also its epistemology are transforming. The ability of generative AI models to create spatial images from textual inputs is accelerating this transformation beyond the aesthetic dimension, extending it into cognitive and technical realms. Bratton's (2021) analysis of platform architecture, on the other hand, demonstrates that artificial intelligence systems are beginning to significantly influence decision-making processes and, consequently, the ways in which space is produced.

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Although the relationship between cinema and architecture is much older, today's digital culture is reinterpreting this connection. Bruno (2002) defines cinema as a form of spatial circulation constructed through surfaces, movement, and affect. Deleuze (1986, 1989) argues that cinema produces space as a field of thought shaped by the fractures, interruptions, and perceptual intensities of time. These perspectives position cinema not merely as a medium that represents space but as one that reconstructs it through aesthetic and cognitive processes.

The media environments of the digital age redefine space across physical, visual, and computational planes. Baudrillard’s (1994) notion of hyperreality and Manovich’s (2001, 2013, 2020) theories of software aesthetics and new media demonstrate that space is transforming into a hybrid structure through the convergence of image, data, and algorithmic processes. In this context, speculative space emerges as a mode of spatial thinking that oscillates between physical reality and digital representation, transforming space from a fixed entity into a relational, computational, and sensory process of becoming.

This study is designed as a conceptual and theoretical analysis and proceeds through literature review and conceptual synthesis methods. The aim is to propose a new regime of spatial thinking at the intersection of cinema, artificial intelligence aesthetics, and architecture. Furthermore, the concept of speculative space is not only considered as a new representational technique but also as a holistic framework that explains the ontological, epistemological, and aesthetic transformation of architecture.

Literature Gap: An Interdisciplinary Theoretical Deficiency

There is an extensive theoretical literature on the spatial modes of production in cinema. Bruno's (2002) surface and affect-based approach, Deleuze's (1986, 1989) distinction between movement-image and time-image, and Virilio's (1989) analyses of speed and perception have intensely discussed cinematic space. Similarly, there are powerful studies in the field of digital design and artificial intelligence that examine the algorithmic production of space: Carpo's (2017) discussion of data-driven design, Manovich's (2013) software aesthetics, and Bratton's (2021) computational infrastructures model are cornerstones of this literature. Paglen (2019) detailed the political and aesthetic consequences of machine vision processes.

However, these two major areas - cinematic production and artificial intelligence-generated space - have largely developed as independent lines of research in the literature. Studies examining digital animation and game spaces (Betancourt, 2020; Champion, 2016), while discussing the experiential nature of space, have not evaluated these forms of production alongside either film theory or artificial intelligence aesthetics.

Therefore, there are three main gaps in the existing literature:

1. A conceptual link between cinematic space theories and AI-generated spatiality has not been established
2. Digital game and animation spaces have not been addressed within a common spatial regime with cinema and artificial intelligence.
3. A holistic spatial ontology explaining the media-based transformation of architecture has not been proposed.

This section seeks to integrate these fragmented domains into a single theoretical framework through the concept of speculative space. It proposes rethinking space as a relational formation emerging from the intersections of cinematic sensation, digital atmosphere, and algorithmic production. Speculative space, therefore, provides an original contribution that bridges conceptual, ontological, and aesthetic dimensions within this interdisciplinary discourse.

The Space of Cinema: A Sensory and Conceptual Production

Cinematic space, unlike the classical logic of architectural representation, is a production area where sensory, perceptual, and narrative processes intersect. Bruno (2002) interprets cinema as a spatial circulation constructed through surface, rhythm, and affect. This approach turns the film-watching experience into a physical orientation.

Deleuze's concepts of the movement-image and the time-image (1986, 1989) provide a fundamental framework for explaining how cinema transforms space. While space is organized through active continuity in the movement-image regime, it is constructed through interruption, stillness, and cognitive intensity. Thus, cinematic space becomes a fluid and fragile entity rather than a fixed architectural presence.

In cinema, space ceases to be merely the stage for the narrative and becomes the carrier of emotion, movement, and thought. In this way, cinema expands the tradition of visual representation in architecture, reconstructing space as a temporal and experiential process. The atmospheric spaces in Tarkovsky's film Stalker (1979) or the body-space dissolution in Cronenberg's film eXistenZ (1999) clearly demonstrate that cinema is a production that reconstructs space both on a sensory and intellectual level.

In this context, Virilio's (1989) analyses of speed, image, and modern perception hold a decisive place in the relationship between cinematic space and technology. According to Virilio, cinema produces the aesthetics of speed; therefore, space is no longer just a field to be seen, but also an interaction between technological speed and perception. This understanding shows that cinema not only represents space but transforms it into a field of perceptual experience.

The cinematic spaces in these examples can be read as concrete manifestations of Deleuze's concept of the “time-image”, because these films invite the viewer not only into a narrative but also into the spatial formation of thought and perception. Cinematic space thus transcends the forms of representation in architecture, such as drawings, plans, or models, becoming an experiential “space of becoming.” In this context, cinema not only provides architecture with form but also the possibility of thinking through time, movement, and emotion.

The aim of this section is to read cinema not only as an art form but also as a mode of production that transforms the ontological nature of space. Cinematic space constitutes the sensory-narrative component of speculative space theory, and this component will intersect with the computational aspect of artificial intelligence-based spatial understanding in later sections.

Space Generated by Artificial Intelligence: Algorithmic Aesthetics and Hyperreality

Generative AI models bring space production into a computational aesthetic realm. In this new environment, architectural production is transforming into a cognitive system based not only on human intuition but also on data relationships, statistical patterns, and algorithmic processing chains. The AI space is influenced not only by the designer's intentions but also by the algorithm's data structures, classification processes, and biased learning mechanisms.

Carpo's (2017) data-driven design discussion illustrates how this transformation expands architecture through intuition, speed, and diversity. This process, which Carpo calls the "second digital turn," suggests that the architect is no longer just a form-maker, but has become an organizer of data and a curator of algorithmic decisions.

Manovich's (2013) software aesthetics explains that spaces generated by artificial intelligence operate not with the logic of cinematic montage, but with the logic of algorithmic processing. This signifies a transformation where the representation of space is replaced by operational production. Therefore, space generated by artificial intelligence is no longer a representational surface; it is a system that transforms the data itself into spatial form.

Baudrillard's (1994) concept of hyperreality reveals that artificial intelligence spaces, rather than copying physical reality, offer an alternative authenticity to it. These hyperrealistic spaces, while seemingly resembling reality, are entirely simulation-based; the experience exists in an intermediate plane between "reality" and “computation.” Therefore, AI-generated space is not just a visual product, but also an epistemological experience.

Paglen's (2019) machine vision aesthetic demonstrates how AI spaces internalize data, biases, and categorical errors. According to Paglen, artificial intelligence systems produce a political redefinition of visibility by extending the act of "seeing" beyond the human gaze. This perspective transforms space into an entity that is not only seen, but also classified and calculated.

Bratton's (2021) discussion of platform architecture, on the other hand, states that artificial intelligence produces space not only visually but also as a logic of governance. Bratton argues that digital infrastructures are transforming into "spatial organisms"; in this context, artificial intelligence not only represents architecture but also reconstructs it as the spatial outcome of data flows, algorithmic stability, and network economies.

Kate Crawford's (2021) work, Atlas of AI, reminds us that behind the production of artificial intelligence lie not only algorithmic processes, but also material infrastructures, energy sources, and geopolitical relationships. In this respect, artificial intelligence space is both an aesthetic and ecological phenomenon; it is a global spatial form that extends from data centers to screen surfaces.

In conclusion, AI-generated space can be defined as more than just an aesthetic representation; it is a form of computational existence. These spaces create a hybrid field where data, speed, and algorithmic processes intersect with sensory experience. In this context, cyberspace constitutes the computational and hyperreal component of speculative space theory.

Speculative Space Theory: A New Inter-Plane Between Cinema and Artificial Intelligence

Speculative space is a new mode of spatial thinking that emerges from the interaction between the sensory-narrative production principles of cinema and the computational-algorithmic aesthetics of artificial intelligence. This regime allows space to be understood not merely as a represented surface or experienced volume, but as a "field of becoming" that oscillates between data, image, narrative, and calculation. In this context, space ceases to be a physical object and becomes a dynamic that is constantly reconstructed among images, atmospheres, data structures, and algorithmic processes.

Bruno's (2002) cinematic space based on superficiality and affect, along with Deleuze's (1989) concept of time-image constructed with discontinuities and intellectual intensity, forms the sensory component of speculative space. Paglen's (2019) machine vision aesthetics and Bratton's (2021) computational infrastructure theory, on the other hand, explain the algorithmic dimension of speculative space. Wigley's (2001) and Colomina & Wigley's (2016) observations that architecture has evolved alongside media technologies indicate that speculative space is a contemporary extension of this historical media continuity. Thus, speculative space is not merely an interface between cinema and AI; it is the new ontological ground of architecture shaped by media conditions.

The concept of speculative space also bears traces of the ideas of speculative realism and new materialism, because here “space” is no longer a representation dependent on the human subject, but a system that exists in its own materiality, givenness, and imaginability. In this sense, speculative space blurs the boundaries between subject and object, representation and reality, and the physical and digital.

Wigley's (2001) observation that architecture has evolved throughout history alongside representational technologies suggests that speculative space is a contemporary extension of this historical media continuity. This line, spanning from analog drawing to digital simulation, from perspective to algorithmic production, proves that architecture has redefined space in every era through its own technical media. Speculative space is the current form of this process; an area of existence that is both visual and computational, emerging from the interaction between cinema and artificial intelligence.

Therefore, speculative space is not merely an interface between cinema and AI; it is the new ontological ground of architecture shaped by media conditions. This ground transforms both the ways in which space is experienced and its production processes. In the next section, the media appearances of this theoretical framework in film, animation, game, and artificial intelligence-based productions will be examined.

The Mediatized Appearances of Speculative Space: Cinema, Animation, Games, and Artificial Intelligence

The theoretical framework of speculative space is not only conceptual; it is also embodied through spatial images produced in contemporary media forms. Cinema, digital animation, gaming spaces, and artificial intelligence-generated visuals offer environments that multiply, transform, and rewrite space without being bound by the physical world. These media forms make visible a new epistemological regime based on the production of space rather than its representation.

In Cronenberg's cinema, space, body, and technology appear as an uncanny entity where the organic and the mechanical intertwine. Shaviro (1993) states that the spaces seen in the films Shaviro (1993), Videodrome (1983), and eXistenZ (1999) possess a post-biological spatial logic; these spaces reveal the permeability between the human body and digital networks, offering early cinematic examples of speculative becoming.

Zilbalodis's film Flow (2024) demonstrates that digital atmospheres can be created that transcend the boundaries of physical reality. In this film, space is no longer a fixed coordinate system; it is a fluid atmosphere created by movement, rhythm, and perceptual intensities. Betancourt (2020) explains the intensity of the digital atmosphere by arguing that animation offers new spatial experiences through emptiness, speed, and superficiality. In this context, animation reproduces sensory reality as a computational surface.

Game spaces, on the other hand, have an interactive rewriting process. Champion (2016) argues that the space of game worlds not only represents but also reconstructs itself through the player's physical and visual interaction. Assassin's Creed: Revelations (2011) reproduces the spatial memory of Istanbul as a dynamic surface of cultural memory, a process closely related to Assmann's (2011) theory of cultural memory. Games thus transform space into an area of both historical and physical participation; the meaning of space is constantly reproduced through interaction, speed, and memory.

Artificial intelligence-generated spatial images represent the most contemporary and original appearance of speculative space. Paglen (2019) shows that AI images carry data biases, classification processes, and machine aesthetics. Steyerl (2021), on the other hand, draws attention to the political nature of digital images and how machine vision regimes transform social perception. The hyperreal atmospheres in these images reveal that artificial intelligence is creating a new spatial reality.

These media forms point to a common conclusion: space is no longer a static object, but a process that is produced, calculated, experienced, and reproduced. Speculative space emerges as a field of becoming that is constantly reconstructed at the intersection of these processes, between cinematic sensation and algorithmic calculation.

Discussion: The New Ontological Framework of Architecture

The intersection of cinematic, digital, and algorithmic processes necessitates a rethinking of the ontological foundations of architecture. Space is transforming from a fixed physical entity into a relational, fluid, and media-based field of formation. This transformation is radically changing both architectural design tools, representation regimes, and the role of the designer subject.

Carpo's (2017) computational design approach shows that the architect is no longer a singular form producer, but rather a manager, curator, and organizer of algorithmic processes. This situation reveals that design has become a common composite of data, algorithms, and human-machine interaction, rather than a creative intuition. AI-generated spaces make it clear that architectural thinking is moving away from a human-centered perspective toward a human-machine partnership.

Wigley's (2001) observation that architecture has always coexisted with media technologies indicates that in today's media ecology, architecture is now shaped by tools such as cinema, game engines, and artificial intelligence. This new media environment transforms architecture from a mere art of construction into an intellectual practice born from the interaction of information, image, and algorithm.

Speculative space is positioned as the conceptual framework for this transformation. By redefining the forms of representation, production, and experience in architecture, it allows us to see space not as a fixed entity, but rather as a process, a becoming, and a field of interaction. Therefore, speculative space should be considered a contemporary paradigm that explains the media-based ontology of architecture.

As a result, space is no longer an object to be built; it is an entity that is experienced, simulated, calculated, and constantly reconstructed. This new ontology transforms architecture into a discipline that considers it not only through material and form, but also through data, speed, visuality, and perception.

Conclusion

This study, by examining the concept of speculative space through cinema, animation, games, and AI-generated images, has comprehensively revealed the evolving nature of architecture. Speculative space demonstrates that space is not merely physical, but a relational reality shaped by images, data flows, atmospheres, and algorithmic processes.

When cinematic time-space, digital atmosphere, the interactive structure of the game space, and artificial intelligence's hyperrealistic productions are considered together, it is clear that architecture can no longer be explained by a single mode of representation. Architecture is transforming into an interdisciplinary practice of thinking; the designer is becoming less a form producer and more a process manager, meaning curator, and algorithmic collaborator.

The concept of speculative space offers a fundamental theoretical tool for understanding how architecture is produced, experienced, and perceived today. This concept can be considered a powerful intellectual framework that will shape the future epistemological and ontological directions of architecture. As this theoretical line, extending from cinema to artificial intelligence, demonstrates, space is no longer entirely human-made nor completely digital; it is a hybrid reality formed by the simultaneous existence of both.

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CHAPTER 8

MULTI-CRITERIA ANALYSIS OF CAST-IN-SITU AND PREFABRICATED REINFORCED CONCRETE SYSTEMS IN POST-DISASTER RECONSTRUCTION: A FUZZY-TOPSIS APPLICATION

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Introduction

When discussing the critical task of post-earthquake reconstruction in areas that have been severely impacted, the scale of the rebuilding of urban centers is being predominantly managed by large, state-sponsored entities, such as TOKİ. Empirical research and coverage in the news shows that the resources, including established concrete batching plants and readily available construction machinery, available at the local level are barely

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sufficient to meet the scale and tight deadlines of this colossal undertaking. One area of hope in getting the reconstruction back on track is the adoption of district-level production and deployment of precast concrete components, and bringing in the necessary construction materials from neighboring provinces. This study now forces us to weigh the relative merits of two main structural approaches: traditional site-based construction with cast-in-place, and the pre-stressed assembly of pre-fabricated building components. It zeroes in on a pressing research query, is the traditional approach or prefabricated components assembly is the key to accelerated recovery. Taking practical measures to put these methods head-to-head, it also identifies the essential metrics to tell them apart.

Literature Review

Ten fundamental criteria were distilled from a thorough literature review, when comparing cast-in-place and precast reinforced concrete structures. These were chosen as they reflect the most significant technical, economic, environmental and performance aspects in the industry and academic literature, and therefore enable a broad and fair comparison of the two systems, looking into different phases of the structural life cycle, where criteria such as post-disaster responsiveness, long-term sustainability, construction efficiency and inherent risks come into play. The ten selected criteria are:

1. Construction Time: The total duration required for project completion (Owusu-Manu et al., 2012).
2. Initial Construction Cost Estimate: The total projected capital expenditure anticipated at the project's design inception (Jung et al., 2020).
3. Life Cycle Cost (LCC): Defined as the net present value of a building's cost over its service life, encompassing

initial construction, maintenance, operating costs, and other expenses (Smith & Kassem, 2018).

4. Energy Efficiency: The imperative to minimize energy consumption during construction activities, equipment utilization, and material processing while maintaining required construction quality (Wang, Li, & Tam, 2018).
5. Seismic Performance: The structural capacity to endure seismic ground motions while preserving safety and maintaining operational functionality (Priestley, Calvi & Kowalsky, 2007).
6. Transportation Risk: The potential for damage or logistical delays during the conveyance of prefabricated elements from the manufacturing facility to the assembly site, often due to vibration, impact, adverse road conditions, and handling operations (Elias-Ozkan & Sherif, 2006).
7. Environmental Impact: The aggregate Greenhouse Gas (GHG) emissions generated across the building's entire life cycle—material production, construction, use, maintenance, and eventual disposal (Cabeza et al., 2014).
8. Maintenance and Repair Requirement: The scope of regular upkeep and intervention necessary to address failure, degradation, or performance loss, ensuring the building operates safely and efficiently throughout its designated lifespan (Flanagan, Jewell & Norman, 1989).
9. Functional Availability Period: The total duration for which a structure can fulfill its intended operational function at an acceptable performance standard (International Organization for Standardization, 2017).

10. Waste and Ease of Dismantling: Implicitly covered in the overall assessment, linked closely to Environmental Impact and LCC).

This robust parameter set facilitates a multi-criteria evaluation, spanning economic, environmental, structural, and critical operational/social dimensions. Within this comprehensive analytical structure, the primary objective is to synthesize a data foundation derived from the existing literature, allowing for a comparative analysis of both construction systems based on the established parameters.

Construction Time

- *"Precast concrete systems are completed in a 'shorter time' compared to cast-in-place systems because the elements are manufactured off-site and transported to the site for assembly." (Bhosale & Kulkarni, 2017)*
- *The prefabricated system is "57% more efficient" in terms of labor, providing significant time savings in formwork assembly, reinforcement placement, and concrete pouring." (Shang et al., 2022)*
- *"The use of prefabricated systems reduces the project duration by an average of "30–40%." (Rajagopal, 2020)*
- *"Production that takes 103 days with in-situ casting is reduced to "48 days" with the prefabricated system." (Sharifi et al., 2021)*
- *"Prefabrication ensures schedule security by reducing weather-related risks." (Jaillon & Poon, 2007)*

Initial Cost

- *"Direct and indirect costs in the prefabricated method are "slightly lower" than in the cast-in-place method." (Ndung'u & Ouma, 2024)*
- *"Prefabricated buildings have reduced the cost per square meter by "10.62%" compared to the traditional system; the total construction cost has decreased by 17.08%." (Wang et al., 2020)*
- *"Prefabricated slabs are on average "23.22% cheaper" than cast-in-place slabs." (Asamoah et al., 2016)*
- *"The most significant barrier to the widespread adoption of prefabrication is the "high initial investment cost." (Xue et al., 2017)*
- *"Precast columns are on average "21.4% less expensive" than cast-in-place columns."(Hao et al., 2018)*

Life Cycle Cost (LCC)

- *"The prefabricated method has a "lower economic and environmental impact" over its life cycle compared to cast-in-place systems." (Vasishta, 2020)*
- *"Prefabricated structures with sandwich panel systems have a "21% lower life cycle cost" compared to cast-in-place systems." (Vasishta, 2020)*
- *"Prefabricated systems offer a "lower total life cycle cost" due to their short construction time and low maintenance costs." (Kamali & Hewage, 2016)*

- *"Compared to on-site production, factory-produced elements create "less environmental burden." (Alshamrani, 2022)*
- *"Prefabricated floors perform better than cast-in-place systems in functional and environmental assessments." (Wang et al., 2018)*

Energy Efficiency

- *"Prefabricated buildings have reduced total energy consumption by 7.54% compared to cast-in-place buildings." (Li et al., 2022)*
- *"Prefabricated systems reduce costs and energy consumption while also shortening project duration." (Zhou et al., 2023)*
- *"Prefabricated systems offer significant advantages in airtightness and production precision." (Hu et al., 2025)*
- *"Factory production increases energy performance by reducing the margin of error." (Wang et al., 2018)*
- *"Prefabrication is an effective method that enhances environmental performance." (Wang et al., 2020)*

Seismic Performance

- *"The seismic performance of prefabricated systems is 'better than cast-in-place' under equivalent seismic conditions." (Liu & Du, 2023)*
- *"Prefabricated joint elements demonstrate a "better strength reserve" compared to cast-in-place elements at the end of loading." (Xi et al., 2024)*

- *"The differences between prefabricated frames and traditional reinforced concrete frames are significant." (Ferrara et al., 2016)*
- *"Prefabricated joint specimens using UHPFRC have demonstrated high seismic performance." (Xi et al., 2024)*
- *"Quality control in prefabricated systems reduces the need for post-earthquake repairs." (Zhao & Li, 2022)*

Transportation Risk

- *"Transporting prefabricated elements can, in some cases, reduce environmental benefits." (Li et al., 2022)*
- *"The transportation and assembly process increases vibration and alignment risks; these risks are "lower" in cast-in-place systems." (Yu et al., 2020)*
- *"Transportation of prefabricated elements is a significant factor determining the environmental impacts of the system." (Li et al., 2022)*
- *"The transportation process is a weak link, especially in remote areas." (Chai et al., 2021)*
- *"Transportation of prefabricated building modules creates additional mechanical stress and damage risk on the modules." (Valinejadshoubi et al., 2022)*
- *"In prefabricated construction, transportation and logistics processes are considered among the significant risk factors." (Anaç et al., 2023)*

Environmental Impact

- *"The prefabricated facade system performed "6.3% better" in terms of carbon emissions." (Dong et al., 2016)*
- *"Prefabricated structures reduce greenhouse gas emissions by "14.10%" compared to cast-in-place structures." (Zhou et al., 2023)*
- *"Carbon emissions in prefabricated systems are "86 kg less per square meter" compared to cast-in-place structures." (Li et al., 2022)*
- *"In some cases, the carbon impact of modern production methods remains "negligible." (Hasik et al., 2021)*
- *"Prefabricated systems offer more environmentally friendly results in overall life cycle impacts." (Kamali & Hewage, 2016)*

Maintenance and Repair Requirements

- *"Although initial costs are high, operating and maintenance costs are "lower" in prefabricated systems." (Vasishta, 2020)*
- *"Factory conditions "significantly reduce" defects that occur in on-site casting." (Hu et al., 2025)*
- *"Maintenance costs in prefabricated systems are "lower" over a 30-year period." (Kamali & Hewage, 2016)*
- *"The quality control advantage "reduces repair frequency" in prefabricated structures." (Wang et al., 2018)*

- *“Many LCCA studies show that maintenance requirements are “lower” in prefabricated systems.” (Aiemrod & Kokkaew, 2024)*

Functional Availability Time

- *“The FEMA P-58 model enables “functional comparison” between systems by measuring component damage and loss of use.” (FEMA, 2021)*
- *“Repair times are ‘shorter’ in prefabricated systems, and rapid functional recovery is achieved through standard replacement methods.” (Terzic et al., 2021)*
- *“Tensioned prefabricated joints provide ”less permanent displacement“ and ‘faster’ functional recovery.” (Ertürk, 2025)*
- *“Replaceable joint designs “significantly reduce operational interruptions.” (Zhang & Pan, 2019)*
- *“Advanced modeling enables “more accurate time estimates” in prefabricated systems.”*

Waste and Ease of Dismantling

- *“Prefabricated systems “reduce” construction waste and “increase” the reuse of building elements.” (Kamali & Hewage, 2016)*
- *“Prefabricated flooring is more advantageous in terms of end-of-life reuse potential.” (Wang et al., 2018)*
- *“Compared to cast-in-place systems, prefabricated construction generates less waste.” (Dong et al., 2016)*
- *“Prefabricated systems are more flexible in demolition planning.” (Zhou et al., 2023)*

- *“Logistical burden is lower during demolition in modular systems.” (Zhao & Li, 2022)*

A synthesis of the literature indicates that even if numerical data isn't consistent, the qualitative descriptions that researchers use, such as “decrease”, “increase” and “more effective” tend to agree on the same criteria, when comparing the effects of interventions. Coming racing straight from the data isn't always possible, so researchers have to methodically collect and reorganise the bits of the literature that they do have, and make it possible to evaluate and quantify. Well-known is that the number of parameters you choose can also be really important, and needs to cover both the social and technical aspects of any evaluation. Recognizing the necessity to model these inherently uncertain and linguistic comparisons mathematically, Fuzzy-TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) is adopted as the appropriate multi-criteria decision-making (MCDM) method, a standard practice in the international literature for solving similar complex problems. The Fuzzy-TOPSIS method allows qualitative expert opinions and literature data to be converted into fuzzy logic membership functions for holistic analysis, thereby providing a final performance ranking based on proximity to the ideal solution.

Methodology

In this section, the 10 parameters used in the multi-criteria comparison of prefabricated and cast-in-place reinforced concrete systems have been quantified based on qualitative assessments in the literature. Qualitative statements for each criterion, taken from different academic sources, were coded with “L–M–H–VH” linguistic values according to the Chen (2000) scale and expressed as triangular fuzzy numbers (TFN). The verbal equivalents of the literature data and TFN values may vary depending on the word choices specific to the study. For this reason, the average of the most academically reliable literature containing these comparisons was taken. Subsequently, the final fuzzy weights were created by taking the arithmetic mean of the lower, middle, and upper values (l, m, u) of each criterion.

Alternatives and Criteria

Alternatives:

A_1 = Reinforced Concrete, A_2 = Prefabricated Module

Criteria (C):

C_1 = Construction Time,

C_2 = Initial Cost,

C_3 = Life Cycle Cost,

C_4 = Energy Efficiency,

C_5 = Seismic Performance,

C_6 = Transportation Risk,

C_7 = Environmental Impact,

C_8 = Maintenance-Repair,

C_9 = Functional Usability,

C_{10} = Waste and Demolition Ease

Construction Time (Construction Time)

"Completed in a shorter time" (Bhosale & Kulkarni, 2017)

VH (0.75, 1.00, 1.00)

"57% more efficient" (Shang et al., 2022)

→ VH (0.75, 1.00, 1.00)

"reduces by 30–40%" (Rajagopal, A, 2020) →

VH (0.75, 1.00, 1.00)

“reduces from 103 days to 48 days” (Sharifi et al., 2021) →

VH (0.75, 1.00, 1.00)

“improves schedule reliability” (Jaillon & Poon, 2007).”

H (0.50, 0.70, 0.90)

Average TFN: (0.70, 0.94, 0.98) → Very High

Initial Cost

“is slightly lower” (Ndung’u & Ouma, 2024) →

M (0.25, 0.50, 0.75)

“has reduced by 10.62%” (Wang et al., 2020)→

H (0.50, 0.70, 0.90)

“is 23.22% cheaper” (Asamoah et al., 2016) →

H (0.50, 0.70, 0.90)

“high initial investment cost” (Xue et al., 2017) →

L (0.00, 0.25, 0.50)

“21.4% lower” (JVI Inc., 2018) → H (0.50, 0.70, 0.90)

Average TFN: (0.35, 0.57, 0.79) → Medium–High

Life-Cycle Cost

“lower economic impact” (Vasishta, 2020) → H

“21% lower cost” (Vasishta, 2020) → VH

“lower total…cost” (Kamali & Hewage, 2016).”→ H

“less environmental burden” (Alshamrani, 2022) → H

“better performance” (Wang et al., 2018) → VH

Average TFN: (0.60, 0.82, 0.94) → High

Energy Efficiency

All studies (Li et al., 2022; Zhou et al., 2023; Hu et al., 2025; Wang et al., 2018; Wang et al., 2020) indicate that prefabricated structures demonstrate high performance by reducing energy consumption.

Average TFN: (0.50, 0.70, 0.90) → High

Seismic Performance

Prefabricated systems have been evaluated with descriptions such as “better performance” (Liu & Du, 2023), “high seismic performance” (Xi et al., 2024), and “significant differences” (Ferrara et al., 2016).

Average TFN: (0.65, 0.88, 0.96) → High–Very High

Transport Risk

“may reduce advantages” (Li et al., 2022) → M

“increases risks” (Yu et al., 2020) → H

“is an important factor” (Li et al., 2022) → H

“is a weak link” (Chai et al., 2021) → L

“add…risk of damage” (Valinejadshoubi et al., 2022) → L

Average TFN: (0.25, 0.48, 0.71) → Medium

Environmental Impact

“6.3% better” (Dong et al., 2016) → H

“reduces by 14.10%” (Zhou et al., 2023) → VH

“86 kg less” (Li et al., 2022) → VH

“remains insignificant” (Buildings & Cities, 2024) → L “more environmentally friendly results” (Kamali & Hewage, 2016) → H

Average TFN: (0.50, 0.73, 0.86) → High

Maintenance / Repair Requirements

“lower maintenance costs” (Vasishta, 2020) → H

“reduces defects” (Hu et al., 2025) → H

“less over 30 years” (Kamali & Hewage, 2016) → H

“reduces repair frequency” (Wang et al., 2018) → H

“less need” (Aiemrod & Kokkaew, 2024) → M

Average TFN: (0.45, 0.66, 0.87) → High

Functional Availability

“shorter repair times” (Terzic et al., 2021) → VH

“faster functional recovery” (Ertürk, 2025) → VH

“reduces operational downtime” (Zhang & Pan, 2019) → H

“enables functional comparison” (FEMA, 2021) → H

“more accurate time estimation” (Vahanvaty, 2021) → H

Average TFN: (0.60, 0.82, 0.94) → High

Waste & Deconstruction

“reduces waste” (Kamali & Hewage, 2016) → H

“reuse is advantageous” (Wang et al., 2018) → H

“less waste is generated” (Dong et al., 2016) → H

“more flexible” (Zhou et al., 2023) → M

“logistical burden is lower” (Zhao & Li, 2022)→ M

Average TFN: (0.40, 0.62, 0.84) → Medium–High

Findings

It includes the evaluation of prefabricated modules and cast-in-place reinforced concrete systems using the Fuzzy TOPSIS method within 10 criteria. Triangular Fuzzy Numbers (TFN) were used, all intermediate calculation tables (normalized r̃ and weighted ṽ) were added, and the results were rounded to three decimal places.

Mathematical Notation

A linguistic value $\tilde{A}$ is defined as (l,m,u).

Triangular membership function:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < l \\ \dfrac{x-l}{m-l}, & l \le x \le m \\ \dfrac{u-x}{u-m}, & m \le x \le u \\ 0, & x > u \end{cases}$$

Table 1. Summary Table – Average TFN Values

Criteria	Average TFN (l,m,u)	Verbal Level
Construction Time (C1)	(0.70, 0.94, 0.98)	Very High
Initial Cost (C2)	(0.35, 0.57, 0.79)	Medium–High
Life Cycle Cost (C3)	(0.60, 0.82, 0.94)	High
Energy Efficiency (C4)	(0.50, 0.70, 0.90)	High
Seismic Performance (C5)	(0.65, 0.88, 0.96)	High–Very High
Transportation Risk (C6)	(0.25, 0.48, 0.71)	Medium
Environmental Impact (C7)	(0.50, 0.73, 0.86)	High
Maintenance and Repair (C8)	(0.45, 0.66, 0.87)	High
Functional Usability (C9)	(0.60, 0.82, 0.94)	High
Waste and Disassembly Ease (C10)	(0.40, 0.62, 0.84)	Medium–High

Referance: Produced by the authors

Table 2. Performance of Alternatives

Criterion	Cast in place (l,m,u)	Precast (l,m,u)
Construction Time (C1)	(0.000, 0.250, 0.500)	(0.750, 1.000, 1.000)
Initial Cost (C2)	(0.250, 0.500, 0.750)	(0.000, 0.250, 0.500)
Life Cycle Cost (C3)	(0.250, 0.500, 0.750)	(0.500, 0.750, 1.000)
Energy Efficiency (C4)	(0.000, 0.250, 0.500)	(0.500, 0.750, 1.000)
Seismic Performance (C5)	(0.500, 0.750, 1.000)	(0.250, 0.500, 0.750)
Transportation Risk (C6)	(0.000, 0.000, 0.250)	(0.250, 0.500, 0.750)
Environmental Impact (C7)	(0.000, 0.250, 0.500)	(0.250, 0.500, 0.750)
Maintenance and Repair (C8)	(0.250, 0.500, 0.750)	(0.500, 0.750, 1.000)
Functional Usability (C9)	(0.250, 0.500, 0.750)	(0.500, 0.750, 1.000)
Waste and Disassembly Ease (C10)	(0.250, 0.500, 0.750)	(0.500, 0.750, 1.000)

Referance: Produced by the authors

Normalization (TFN)

Benefit criteria

$$\tilde{r}_{ij} = (\frac{l_{ij}}{u_j^{max}}, \frac{m_{ij}}{u_j^{max}}, \frac{u_{ij}}{u_j^{max}})$$

Cost criteria

$$\tilde{r}_{ij} = (\frac{l_j^{min}}{l_{ij}}, \frac{l_j^{min}}{m_{ij}}, \frac{l_j^{min}}{u_{ij}})$$

This normalization standardizes the different scales of each criterion between 0 and 1.

Weighted Normalization

The TFN value of each criterion is multiplied by the criterion weight:

$$\tilde{v}_{ij} = \tilde{w}_j \otimes \tilde{r}_{ij} = (l_w l_r, m_w m_r, u_w u_r)$$

Thus, the v_ij matrix is obtained.

Fuzzy Positive and Negative Ideal Solutions

Positive ideal (FPIS / A⁺):

$$\tilde{v}_j^+ = (\max_i \ l_{ij}, \max_i \ m_{ij}, \max_i \ u_{ij})\text{benefit}$$

$$\tilde{v}_j^+ = (\min_i \ l_{ij}, \min_i \ m_{ij}, \min_i \ u_{ij})\text{cost}$$

Negative ideal (FNIS / A⁻):

$$\tilde{v}_j^- = (\min_i \ l_{ij}, \min_i \ m_{ij}, \min_i \ u_{ij})\text{benefit}$$

$$\tilde{v}_j^- = (\max_i \ l_{ij}, \max_i \ m_{ij}, \max_i \ u_{ij})\text{cost}$$

Calculation of Distances

Distance formula between TFNs

$$d(\tilde{A}, \tilde{B}) = \sqrt{\frac{(l_A - l_B)^2 + (m_A - m_B)^2 + (u_A - u_B)^2}{3}}$$

The distance of each alternative from FPIS and FNIS

$$\boldsymbol{D_i^+} = \sqrt{\sum_{\boldsymbol{j}} \quad \boldsymbol{d(\tilde{v}_{ij}, \tilde{v}_j^+)^2}}, \boldsymbol{D_i^-} = \sqrt{\sum_{\boldsymbol{j}} \quad \boldsymbol{d(\tilde{v}_{ij}, \tilde{v}_j^-)^2}}$$

Closeness Coefficient (CC)

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \in [0,1]$$

Table 3. Final Calculated Distances and Closeness Coefficient

Alternative	D+ (Distance from Ideal)	D− (Distance from Anti-Ideal)	CC (Closeness Coefficient)
Cast-in-Place RC	0.499	0.210	0.296
Precast Module	0.210	0.499	0.704

The alternative with the higher CC value is preferred. In this study, the prefabricated module was closer to the positive ideal solution. The results of the evaluation using the Fuzzy-TOPSIS method show that prefabricated modular systems are much closer to the ideal solution (CC = 0.704). It shows that prefabricated reinforced concrete modules offer distinct advantages over cast-in-place reinforced concrete systems in post-disaster reconstruction processes. Prefabricated modules performed well in terms of construction time, energy efficiency, life cycle cost, maintenance and repair requirements, and functional usability. It has been determined that prefabricated joints show better resistance in earthquake performance and offer a more sustainable option in terms of environmental impact and waste management. However, transportation risk has emerged as an important factor that needs to be optimized in prefabricated systems. Overall, the analysis results confirm that prefabricated modules offer a fast, reliable, and functional solution after a disaster.

Conclusion and Recommendation

In this paper, the performance of cast-in-place and prefabricated reinforced concrete systems in post-earthquake reconstruction was comparatively productivity-wise studied in terms of productivity, which, through Fuzzy-TOPSIS method led to analysis of ten affecting parameters over the process. When converting literature-derived information into tangible parameter classes and analyzing its language properties, the advantages of precast reinforced concrete modules in terms of construction speed, cost of the life cycle, energy efficiency and functional usability after a disaster become clear. Cast-in-place reinforced concrete systems, despite their structural reliability, are on the downside due to the lengthy production times, localised resource requirements, and being unable to cope well with post-disaster capacity issues. Coming hurrying the risks related to transporting these prefabricated modules is something that needs to be sorted out. Prefabricated systems show that they're capable of delivering a more practical, faster and eco-friendly answer, especially in towns and rural areas in desperate need of rebuilding. The problems associated with vibrations and alignment during transportation can be lessened if the dimensions of the modules are adjusted according to regional road conditions, if the right transport equipment is used and if the routes are well planned. Simplifying production and assembly guidelines in accordance with national regulations, standardizing the way modules are connected, and establishing a uniform system and protocol for all sorts of modules across the country will all increase the efficiency of this system. Larger-scale studies that also examine the social and economic impacts of prefabricated modules will make the method even more applicable to different types of towns and villages, and give a massive boost to sustainable transformation plans after a disaster.

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CHAPTER 9

FROM RAW MATERIAL TO USE: STEEL CONSTRUCTION MATERIAL

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Introduction

Steel offers many advantages over other structural building materials. Its strength provides architectural designs with great flexibility and freedom. This has enabled the creation of unique designs in free forms and desired geometries (Öğüt, 2006).

Steel is the most advantageous building material when considering its load-bearing capacity and density ratio. This property allows for the spanning of wide openings with minimal material by utilizing efficient cross-sections. Additionally, steel exhibits similar values for tensile and compressive strength and demonstrates high resistance to torsional and bending moments. This property allows

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the structure to be up to 50% lighter than a reinforced concrete structure. This reduces the size and cost of the foundation. Furthermore, it helps reduce potential damage by lightening the structure in earthquake zones and areas with weak ground conditions (Güler, 2005).

Steel elements can be reused multiple times. Materials that have reached the end of their service life can be collected as scrap, recycled at a rate of 66%, and used to produce new elements, which can then be reused in construction (Güler, 2005).

Steel is a construction material with industrial quality assurance because it is largely produced in factories under expert supervision and by qualified workers. The fact that its construction is fast and clean provides a significant advantage (Öğüt, 2006).

The purpose of this study is to examine the stages that steel structures, which we frequently encounter today, undergo during the production phase in order to obtain these advantages.

The process of creating structures has evolved with many new materials and techniques from the very beginning to the present day. The selection and use of construction systems are shaped by many factors. Financial reasons, materials, construction time, and labor are among the main factors. In our era, with the advancement of technology and the depletion of natural resources, new building systems and construction techniques using recyclable materials, such as steel, have emerged (Öztürk, 2008).

The study examines the current state of steel construction materials in the production process through a review of the existing literature. The study includes a review of the historical process of steel materials from their earliest examples to the present day and the functions they have undergone in the production stage. The historical development of steel, production methods, processing, and assembly methods of its parts are discussed.

1. The Historical Development of Steel

With the Industrial Revolution, the need for column-free interior spaces with large spans or multi-story high-rise buildings to meet the needs of the growing urban population required the use of high-strength materials in building structures (Öğüt, 2006). The industrial production of iron and its use as the main material in load-bearing systems created a fundamental transformation in the design approach to architecture (Ağaoğlu, 2009). From the past to the present, architects and engineers have followed new products developed with advancing technology and used them in their structures both to meet needs and to develop new design approaches.

Steel-framed structures stand out as high-quality industrial products. From the 18th century to the present day, the development and use of iron and steel materials in line with technological advances has led to significant improvements in the load-bearing systems of buildings (Eren, 2014; Korkmaz, 2019).

The use of steel as a structural element in buildings dates back to the 1700s. Systems enabling the industrial-scale production of steel emerged in 1740 with Benjamin Huntsman's discovery of the crucible smelting method (Öğüt, 2006). The Coalbrookdale Bridge, built over the River Severn in England in 1779, is considered the first large iron structure. With a span of approximately 30 meters, this bridge is notable for its semicircular arch design (Ağaoğlu, 2009).

From the 1830s onwards, the increasing pace of transportation led to a growing need for new structures. Iron first emerged as a material used in bridges, and this experience later paved the way for its use in terminal buildings. In this regard, Robert Stephenson's “Euston Train Station” in London, completed in 1839, with its twelve-meter curved trusses, was one of the first examples of steel terminal structures. (Öğüt, 2006).

In 1841, John Augustus Roebling, an American engineer of German origin, established a factory that produced wire ropes from rolled iron wires. Using these ropes, he built the first suspension bridge over the Monongahela River in 1845 (Ağaoğlu, 2009).

By the 1870s, steel could now be produced on an industrial scale. The first large bridge constructed entirely of steel was built in 1874 in St. Louis, Missouri, over the Mississippi River by James Buchanan Eads. Eads used a design consisting of three arches for this project, and the bridge spans reached approximately 160 meters (Ağaoğlu, 2009).

Towards the end of the 19th century, steel, which was used in bridges and terminal buildings, began to be used in shopping malls and commercial buildings as well. The most important reason for this was the modular work and prefabrication applications obtained from cast iron columns and connections in horizontal and vertical directions. One of the first structures to use prefabrication techniques was the “Galerie d'Orleans” built by Fontaine in Paris's Royal (Öğüt, 2006).

Steel structures have evolved over time and have begun to be preferred in skyscraper projects. The “Home Insurance Building,” constructed in Chicago in 1885 by William Jenney, is considered the first skyscraper with a steel skeleton structure. It is twelve stories high and fifty-five meters tall (Öğüt, 2006). Today, steel is preferred in many types of structures.

2. Steel Production Methods

Steel is an extremely versatile material that can be used in various fields. There are many different types of connections. Steel forms and surface treatments, along with all material parameters, are available in numerous varieties. In addition, steel is an environmentally friendly material as it is recyclable (Hanses, 2015).

Coal, coke, iron ore, and scrap iron are used as raw materials for steel production (Hanses, 2015). Steel is an alloy whose main component is iron and which contains carbon in proportions ranging from 0.002% to 2.14% (Ersöz et al., 2016). Iron is an element that constitutes 5% of the earth's crust, is not hard, can be easily shaped, and has high electrical conductivity (Korkmaz, 2019).

Steel production worldwide is generally carried out in integrated plants using iron ore and coke, or by melting scrap in electric arc furnaces. In addition, production using older technologies such as the open-hearth (OH) method continues in some former Soviet Union countries, but these plants are rapidly disappearing. (Ersöz et al., 2016).

Since steel first began to be used as a construction material, different methods have been used in the production process. Initially, the "Bessemer process" was used, followed by the "Thomas process" and the "Siemens-Martin process." Today, the most common production methods are the "oxygen blowing process" and the "electric arc furnace" method.

- Bessemer Process: Developed by English engineer Henry Bessemer and patented in 1855 (Tüter, 2018). This method involves blowing air into molten iron for approximately 20 minutes. The converter used is positioned vertically, like a blast furnace, and is lined with heat-resistant silica-added firebricks. Thanks to the bedded rollers placed on top, it is a simple pear-shaped vessel that can be tilted when it is necessary to fill it with molten iron, blow air into it, and empty the steel (Öğüt, 2006). The converter can rotate around a shaft passing through its lateral axes, allowing molten iron and separated slag to be removed from the vessel and replaced with new iron (Tüter, 2018).

- Thomas Process: In 1876, Thomas Gillchrist developed a furnace in which sulfur and phosphorus in raw iron could also be burned. The difference between this furnace and the Bessemer furnace is that its lining is made of dolomite bricks instead of silica bricks, and sufficient limestone is added to the converter during operation (Öğüt, 2006). This addition allows it to retain phosphorus and sulfur. However, the steel produced here does not yet have the desired hardness and formability because it comes into contact with high amounts of nitrogen gas in the converter during the production stage (Tüter, 2018).
- The Siemens-Martin process is also known as the reverberatory furnace. It consists of a long, flat structure with walls and a ceiling lined with fire-resistant bricks. The furnace is heated with gas. There are chambers on both sides. Air is blown into one of the chambers. During operation, the hot gases generated inside the furnace pass through the other chamber, heating it, and are then expelled through a tall chimney. Approximately every 20 minutes, the direction of the air and hot gas flow in the furnace is reversed. In this way, fuel and air are first supplied through one chamber while hot furnace gases exit through the other chamber. Twenty minutes later, when the flow is reversed, the air blown into the furnace passes through the chamber through which the hot gases have passed. Thus, the air blown into the furnace is preheated and increases the internal temperature (Öğüt, 2006). With this method, the iron and limestone loaded into the furnace are melted, and the carbon content in the iron is brought to the desired level to produce steel (Elliott, 1992; Tüter, 2018).

2.1. Production of Steel Using the Oxygen Blowing Method

The most preferred method is carried out in integrated iron and steel plants. Essentially, this method involves removing excess carbon from iron-oxide ores by converting it into carbon monoxide with oxygen, followed by alloying and deoxidation processes (Url 1).

During the production process, iron rich in oxide is mixed with lime and smelted in blast furnaces to obtain iron with the help of energy. At the end of this process, pig iron containing high carbon and carrying phosphorus and sulfur is produced. Pig iron has a brittle structure and cannot be used as raw material. The molten pig iron is transferred to a converter where oxygen is blown in and other materials are added. This process reduces the carbon, sulfur, and phosphorus content of the pig iron, resulting in a more workable material (Url 1).

Elements other than carbon are added according to the desired properties of the steel. Elements such as aluminum and silicon are also added during the steelmaking process as deoxidizers to remove excess oxygen from the steel (Url 1).

Sulfur combines with the iron element to form the FeS compound. The melting point of the compound is approximately 1,094 °C. During rolling, FeS compounds that turn into liquid inside the steel, which is in a solid state, cause a condition called “hot tearing.” To prevent this, sulfur removal is performed before the rolling stage, or manganese is added to the alloy to form MnS, thereby preventing hot tearing (Url 1).

After all these processes, the liquid steel is transferred to rolling mills and cast into the desired shapes using the continuous casting method. Following this casting process, the steel begins to solidify. Subsequently, depending on the mechanical and surface properties required for the steel's final use, the material undergoes hot rolling or cold rolling processes. Finally, steel products undergo packaging and other final processes to reach their final form and are made available for use (Url 1).

2.2. Production Method Using an Electric Arc Furnace

In this furnace, scrap suitable for the composition of the steel to be produced is used. In electric arc furnaces, scrap steel can be used directly because very high temperatures can be achieved. After being melted, the scrap undergoes processes similar to those in integrated steel mill processes. Subsequently, continuous casting or ingot casting processes, rolling mills, etc., are carried out as in integrated facilities. These processes are carefully controlled to ensure that the quality and properties of the steel reach the desired level (Url 1).

3. Processing of Steel

Metal materials can be shaped using different processes. Steel material can be shaped using mechanical methods without breaking due to its crystalline structure. (Eren, 2014; Korkmaz, 2019).

Just as there are different ways to produce steel products, there are also many different methods for further processing these products. A distinction is generally made between hot and cold forming. A range of methods are used in both processes. Hot forming improves the properties of steel and facilitates its processing, while cold forming provides higher strength (Hanses, 2015).

Table 1. Steel Forming Methods

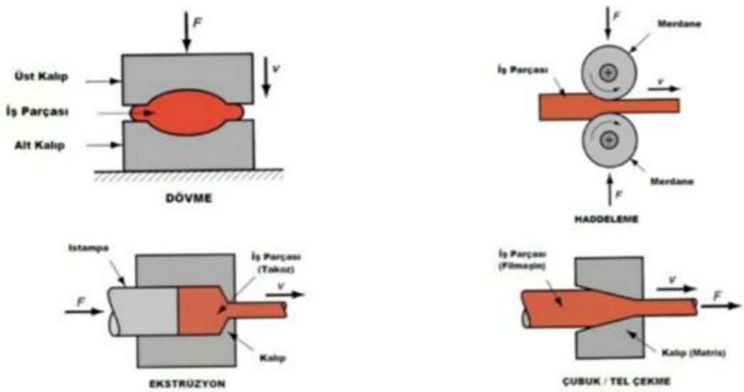
Hot Forming	Cold Forming
Foundry	Drawing
Hot Rolling	Cold Rolling
Press	Press
Forging	Forging
	Processing Processes Bending
	Cold profiling
	Deep Drawing

Reference: Hanses, 2015

- Cast steel is poured into sand molds. Cast steel parts can be welded, but they must first be heated. Cast steel has standardized and defined properties, just like rolled parts. Any shape is possible, thus offering great design flexibility (Hanses, 2015).
- The forging process is performed manually or mechanically using a hammer and anvil or press dies. This method can also produce a wide variety of different shapes. The structure of the steel is altered by forging; the coarse-grained structure is transformed into a fine-grained structure, thereby increasing its strength (Hanses, 2015).
- Rolling improves the structure of steel. A system consisting of cylinders and drums forms the cross-section of steel under high pressure. This process can be carried out at different temperatures. Rolling is considered a more advanced development in steel production (Hanses, 2015).
- Extrusion is typically used for sections that cannot be rolled due to their geometry. A heated block is pressed through a die to obtain the desired shape (Hanses, 2015).

- Bars, reinforcing bars, and wires are produced by drawing. The material undergoes a series of stages in which it is progressively made thinner. Since this process is cold forming, the resulting products have high strength (Hanses, 2015).
- Deep drawing is a method of shaping sheet metal using dies, clamps, and matrices. This process is typically used for the production of sections, grooves, or similar products that are open on one side (Hanses, 2015).

Figure 1: Steel Forming Methods



Reference: Hanses, 2015

Additionally, there are many other shaping methods available through mechanical processing. These include milling, drilling, grinding, sawing, turning, bending, stamping, and folding. These advanced processing methods result in a product known as a semi-finished product, which can then be further processed to form a structural component (Hanses, 2015).

4. Methods of Joining Steel Elements

The design of the connection points of the components forms a fundamental part of the structure. These connections can be standardized or specially designed for complex shapes. When the structure is visible and observable from the outside, the connection points also play an important aesthetic role (Eren, 2014; Korkmaz, 2019). Special connection points can be designed for different architectural shapes or, if desired, details that allow the structure to be dismantled and rebuilt (Öğüt, 2006).

The structure that forms the steel building is created by joining different steel elements together. (Öğüt, 2006). These methods are "riveting," "welding," and "bolt joining."

- Riveting refers to fasteners obtained by pressing round steel, which carry loads through deformation around the hole and shearing effects on the body, and this process is called riveting. (Güler, 2005) Fasteners consisting of a head and a cylindrical body can be used in hot or cold riveting processes. (Öztürk, 2008, Tüter, 2018).

- Welding is one of the permanent joining methods, similar to riveting. Its advantages over riveting include material savings and aesthetic benefits. Hasol (1990; Korkmaz, 2019) states that welding provides significant material savings in steel structures. Furthermore, joining using this method is easier and takes less time. Welded joints have high rigidity, and the strength in the welded area can reach levels close to the strength of the main material (Güler, 2005).

- Bolt (screw) fastening is a detachable fastening device consisting of a cylindrical body with a hexagonal head and a threaded section at the end, and a nut. (Güler, 2005). Nuts are tightened with a wrench to connect the parts (Hasol, 1990; Korkmaz, 2019). This method is the most widely preferred type of connection in the construction industry due to its advantages such as not requiring special materials, being easily applicable in all environmental conditions, and being able to be disassembled and reassembled when necessary (Tüter, 2018).

Figure 2: Methods of Joining Steel Components

Reference: Tüter, 2018

Conclusion

Steel-framed structures stand out as high-quality industrial products. From the 18th century to the present day, the development and use of iron and steel materials in line with technological advances has led to significant improvements in the load-bearing systems of buildings. The use of steel in buildings began in the 1700s.

In contemporary architecture, where the use of steel in structures has increased, it is important to recognize steel as a material and understand the types of joints used with steel structural components. Steel, with its lightweight, flexible, and ductile properties, enables the creation of free-form structures capable of spanning large openings, thereby bringing a sense of freedom to architecture. Steel is an iron-carbon alloy containing less than 2% carbon and can acquire different properties through mechanical and thermal processes. Thanks to its various shaping possibilities and technical properties, this material can be used in different ways.

Steel is currently produced using two active methods. These are: the oxygen blowing production method and the electric arc furnace production method.

The most preferred method is carried out in integrated iron and steel factories. Basically, this method involves removing excess carbon from iron-oxide ores by converting it into carbon monoxide with oxygen and then performing alloying and deoxidation processes. In electric arc furnace plants, scrap suitable for the composition of the steel to be produced is used. In electric arc furnaces, scrap steel can be used directly because very high temperatures can be achieved. After being melted, the scrap undergoes processes similar to those in integrated plant steelworks. Subsequently, continuous casting or ingot casting processes, rolling mills, etc., are carried out as in integrated plants. These processes are carefully controlled to ensure that the quality and properties of the steel reach the desired level.

Just as there are different methods for producing steel products, there are also numerous different methods for further processing these products. A distinction is generally made between hot and cold forming. A range of methods is used in both processes. Hot forming improves the qualities of steel and facilitates its processing, while cold forming provides higher strength. Methods include casting, forging, rolling, extrusion, and deep drawing.

The structure that forms the steel structure is created by joining different steel elements together. These methods are "riveting," "welding," and "bolting."

As a result, based on the data obtained from the literature review, when examining the historical development of steel, its production process, production methods, processing, and assembly techniques of its components, it is observed that steel offers multiple detailing options and assembly techniques that provide designers with flexibility; it also offers the possibility of fast, reliable, recyclable, and flawless completion.

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CHAPTER 10

ASSESING SITE SELECTION AND INFRASTRUCTURE RISK FACTORS FOR POST-DISASTER TEMPORARY HOUSING UNITS-ENTROPY-BASED TOPSIS FRAMEWORK

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2. GÜLDEN GÜMÜŞBURUN AYALP[2]

Introduction

Disasters are catastrophic events that harm individuals, economies, and the overall stability of affected communities. In recent years, natural disasters have caused over 3.3 million deaths and $2.3 trillion in economic damage (Zhao et al., 2017). Among natural disasters, earthquakes have caused the most remarkable human and economic losses (Yüksel & Akbel, 2023). Although earthquakes cannot be prevented, their adverse effects can be mitigated through disaster management planning, social awareness, and effective post-disaster response.

The most urgent need in the post-earthquake period is shelter (George, Guthrie, & Orr, 2023; Lines, Walker, & Yore, 2022; Zhao

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et al., 2017). Post-disaster temporary housing units (*PDTHUs*) are vital in providing immediate shelter and support to displaced populations, ensuring their safety and dignity during the post-disaster recovery process (Afkhamiaghda et al., 2021; Lines et al., 2022). Given the increasing frequency and severity of disasters, the need for well-planned *PDTHUs* has become more critical than ever. The unpredictable nature of earthquakes typically precludes timely warnings and evacuations, making it difficult to mitigate damage; hence, emergency shelter arrangements often become a post-earthquake issue. Therefore, pre-earthquake planning is crucial in ensuring an efficient and timely implementation of emergency shelters after an earthquake.

Quarantelli (1995) examined post-disaster sheltering within four main categories: emergency sheltering, temporary sheltering, temporary housing, and permanent housing. Emergency sheltering refers to the initial arrangements in which disaster victims stay outside their permanent homes for short periods, such as several hours or overnight. Temporary sheltering refers to short-term accommodations where affected individuals reside after the immediate danger has passed but before they re-establish their household routines. Temporary housing refers to a phase in which disaster survivors begin to rebuild their domestic lives, typically lasting for several months, until they can move into a permanent residence. Permanent housing represents the final stage, where individuals return to repaired or rebuilt homes or relocate to new, permanent settlements. These four categories offer a valuable conceptual framework for understanding the complexity of post-disaster sheltering processes.

As urbanization increases, disasters pose a growing threat to infrastructure systems that support societal functioning (Deelstra & Bristow, 2023). The performance of PDTHUs depends largely on robust infrastructure and appropriate site selection, yet these aspects remain underexplored in the literature.

Previous studies have primarily focused on the design (Cerrahoğlu & Maden, 2024; Hendriks & Stokmans, 2024; Rahmayati, 2016) and social integration (Mutch, 2023; Rahill, Ganapati, Clérismé, & Mukherji, 2014; Xiang, Welch, & Liu, 2021) aspects of temporary housing. However, despite extensive research on temporary housing, infrastructure-related and site-selection risks remain underexplored, particularly in systematic prioritization. This gap in the literature underscores the need for a systematic approach to identifying, assessing, and prioritizing risks in this field associated with *PDTHUs* (Peng et al., 2018; Zhao, Lee, & Yu, 2021). A better understanding of these risks is critical for enhancing PDTHU performance and resilience.

This study aims to fill this gap by systematically identifying and prioritizing site selection and infrastructure risks using a systematic literature review (SLR) and the entropy-based TOPSIS method. The framework intends to inform more resilient and sustainable PDTHUs solutions.

Literature Review

Identifying and assessing risk factors for PDTHUs is crucial for effective emergency planning, particularly in the aftermath of earthquakes. In recent years, site selection and decision-making processes have gained increasing attention in disaster response research (Çetinkaya, Özceylan, & Işleyen, 2021; Hosseini, Ghalambordezfooly, & de la Fuente, 2021; Omidvar, Baradaran-Shoraka, & Nojavan, 2013).

Numerous studies worldwide have explored site selection criteria and their applications, emphasizing the global significance of this research (Hosseini, De La Fuente, & Pons, 2016; Trivedi, 2018). Trivedi (2018) proposed a multi-criteria decision-making

(MCDM) framework to evaluate and rank various criteria for shelter location selection. Similarly, Kilci *et al.* (2015) used a mixed-integer linear programming formulation to determine shelter locations based on ten criteria the Turkish Kızılay identified. Çelik and Erduran (2011) conducted a risk assessment study on earthquake parks using 12 criteria, while Omidvar et al. (2013) proposed a MCDM model for site selection of temporary shelters. Zhao et al. (2017) formulated a multi-objective model for the site selection and allocation of earthquake emergency shelters. Nappi et al. (2019) developed a multi-criteria decision model using nine criteria for selecting and locating temporary shelters, while Çetinkaya et al. (2021) used MCDM analysis tools to identify shelter areas in Syria, creating four scenarios with varying criterion weights.

Among various methodological approaches, the Analytical Hierarchy Process (*AHP*) has been widely adopted as a dominant tool for criterion weighting in related studies. Cheng and Yang (2012) developed a comprehensive evaluation strategy for selecting seismic emergency shelters using *AHP*. Hosseini et al. (2016) established nine criteria for temporary shelter locations and determined the requirement weights using *AHP*. Şentürk and Erener (2017) utilized *AHP* and Geographic Information System (*GIS*) tools for site selection, incorporating six criteria for temporary shelter locations. Chu and Su (2012) combined *AHP*, entropy techniques, and *TOPSIS* to define nine criteria for a fixed seismic shelter evaluation system. Trivedi and Singh (2017) introduced a multi-objective decision model using fuzzy *AHP* for shelter location and relocation. Geng *et al.* (2020) extended this approach by integrating fuzzy *AHP*, fuzzy *TOPSIS*, and multi-objective optimization, identifying six criteria for emergency shelter selection.

Although these studies provide valuable insights, they often overlook the critical role of infrastructure and site selection in the effectiveness of *PDTHUs*. Müller and ElZomor (2024) emphasized that informal housing reliance and insufficient infrastructure exacerbate post-disaster challenges. Tasmen et al. (2023) assessed seismic hazard resilience and proposed strategies to strengthen housing infrastructure. Their study evaluated factors such as speed, redundancy, and resource utilization, providing a basis for enhancing both immediate and long-term infrastructure effectiveness. Aman and Aytac (2022) investigated post-disaster infrastructure's ability to meet community needs, mainly by identifying secure assembly zones. These studies underscore robust infrastructure's importance for rapid recovery and long-term sustainability.

Despite extensive research on site selection criteria, decision-making processes, and infrastructure resilience for emergency shelters and *PDTHUs*, several critical gaps persist, particularly in risk assessment methodologies, interdisciplinary approaches, and context-specific risk evaluations.

- *Lack of Comprehensive Risk Assessments:* While many studies focus on temporary housing, they often fail to conduct a thorough risk analysis of *PDTHUs* locations and infrastructure.
- *Methodological Limitations:* Most previous studies rely on *AHP*, *GIS*, and multi-objective optimization, lacking integration with interdisciplinary approaches that could enhance decision-making frameworks.
- *Insufficient Consideration of Context-Specific Risks:* Existing studies rarely address risks specific to geographical, social, and economic contexts, particularly in disaster-prone regions.

This study fills these gaps by performing a comprehensive risk assessment of PDTHUs using a systematic literature review and the entropy-based TOPSIS method. Additionally, it proposes a holistic, context-aware framework to manage risks associated with PDTHU locations and infrastructure.

Research Methodology

This study aims to prioritize infrastructure and site selection risks in PDTHUs using a systematic literature review and the entropy-based TOPSIS method. The research addresses three main questions:

RQ_1: How do site selection and infrastructure risks affect the sustainability of PDTHUs?

RQ_2: What are the most critical site selection and infrastructure risks?

RQ_3: How can entropy-based TOPSIS effectively rank these risks?

To answer these questions, the methodology included:

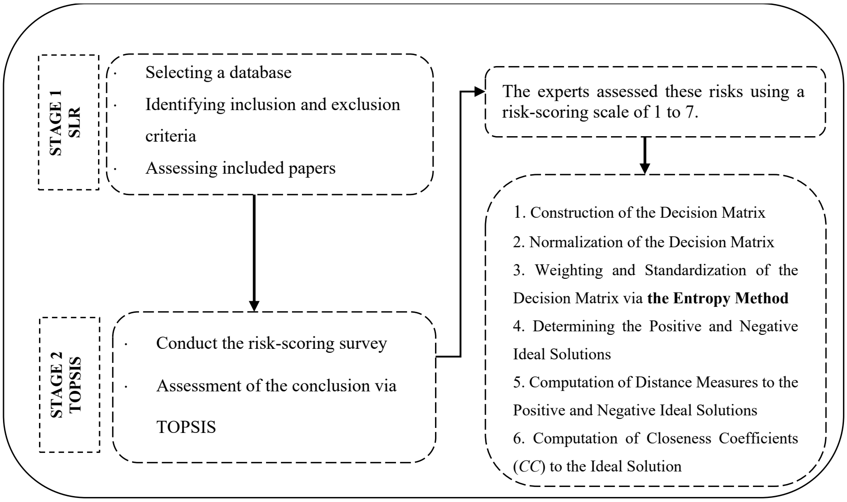
1. Systematic Literature Review (SLR)

SLR was conducted in the Scopus database using keywords related to temporary housing, post-disaster recovery, and infrastructure risks. Following a structured screening process (Wohlin, 2014) to exclude irrelevant publications, 185 articles were retained for analysis, leading to the identification of thirteen risk factors.

2. Risk Assessment with Entropy-Based TOPSIS

These risks were then assessed by experts, who scored them based on probability and impact. The entropy method was used to calculate objective weights, with a focus on criteria that exhibit greater variability. These weights were incorporated into the TOPSIS model to rank the risks. The steps of the TOPSIS method include creating a decision matrix, normalizing the data, applying entropy weighting, identifying ideal solutions, calculating distances, and finally ranking alternatives based on closeness coefficients.

Figure 1. *The schematic diagram of the framework*



Reference: This figure was created by the authors.

Identification of Risks with SLR

Systematic literature reviews *(SLRs)* are crucial for providing accurate and dependable summaries of existing research. To accomplish this, they must be conducted in a systematic, transparent, unbiased, and reproducible way (Denyer, Tranfield, & Van Aken, 2008; Okoli & Schabram, 2010; Tranfield, Denyer, & Smart, 2003). Previous studies have highlighted that well-structured SLRs improve the validity of findings by ensuring consistency and reducing subjective bias (Macpherson & Jones, 2010). In this study, the SLR method was used to identify risk factors related to site selection and infrastructure in post-disaster temporary housing units. The process included defining research questions, setting inclusion and exclusion criteria, searching relevant databases, screening and selecting studies, and synthesizing the findings. This organized approach ensured the collection of relevant, high-quality evidence to determine the final set of risk factors for further analysis.

Scopus was selected as the primary database for its broad multidisciplinary coverage, superior citation tracking, and stronger indexing in high-impact journals, particularly in the social sciences, compared to alternatives like Web of Science (Memisevic and Djipa, 2023; Okudan et al., 2024).

The next phase involves the extraction and filtration of data from the chosen database. The following is the search string that is utilized in the database where the Scopus is stored:

"ALL FIELDS" with the keywords; "Post-Disaster Temp* Hous*" OR "Post Disaster Temp* Hous*" AND "Post-Earthquake Temp* Hous*" OR "Post Earthquake Temp* Hous*" AND "Post-Disaster Reconst*" OR "Post Disaster Reconst*" AND "Risk" AND "Infrastructure" AND "Site Selection."

The database search conducted in July 2025 initially identified 220 articles. After applying filters for time, language, and content, 185 studies remained for detailed review. The analysis of these studies identified thirteen risks related to site selection and infrastructure for temporary housing, summarized in Table 1.

***Table 1**. Risk factors identified through SLR*

ID	Definition of Risk	Sources
R_1	Destruction of existing infrastructure	[1–3]
R_2	Disregarding the geographical conditions of the region designated for temporary housing construction	[4–7]
R_3	Temporary houses are not suitable for expansion in case of need	[8–12]
R_4	Lack of pre-determined land for temporary housing - Difficulty in finding land	[13–16]
R_5	The location of the temporary houses to be built is far away from the existing housing areas.	[17–20]
R_6	Variability of construction time according to the size of the land and the number of houses	[18,21–24]

R_7	Failure to comply with the main road and side road width standards in temporary housing areas	[4–7]
R_8	Disregarding the standards set by institutions (AFAD, FEMA) for site selection	[7,25–29]
R_9	Lack of basic facilities such as schools, markets, and health centers in temporary housing areas	[30–34]
R_{10}	Temporary housing areas require easy access to essential infrastructure services, including electricity, water, and sewerage.	[17,35–39]
R_{11}	Failure to take into account the physical properties of the building elements surrounding the spaces that affect the heat transfer	[10,17,35–37]
R_{12}	Settlement integration problems due to a lack of urban planning	[40–43]
R_{13}	Difficulties in transporting building components and materials due to the logistical inaccessibility of the area where temporary housing will be built	[4–7]

Notes: *[1] Hwang et al. (2014); [2] Aman and Aytac (2022); [3] Tasmen et al. (2023), [4] Ramos and Pereira (2021); [5] Shrestha and Orchiston (2023); [6] De Hoop and Ruben (2010); [7] Oggioni et al. (2019); [8] Cerrahoğlu and Maden (2024); [9] Félix et al. (2015); [10] Montalbano and Santi (2023); [11] Xin et al. (2022); [12] Lines et al. (2022); [13] Hosseini et al. (2016b); [14] Hosseini et al. (2021a); [15] Johnson (2007); [16] Perrucci et al. (2020); [17] Otsuyama et al. (2024); [18] Vahanvati et al. (2023); [19] George et al. (2023); [20] Siriwardhana and Kulatunga (2023); [21] Wang and Ng (2023); [22] Shahzad et al. (2022); [23] Shaikh et al. (2023); [24] Arora (2022); [25] Fayazi and Lizarralde (2013); [26] Félix et al. (2013); [27] Hosseini et al. (2016a); [28] Niu et al. (2012); [29] (Harriss et al., 2020); [30] (Hendriks and Stokmans, 2024); [31] (Mutch, 2023); [32] (Gioiella et al., 2023); [33] (Liu et al., 2022); [34] (Wang et al., 2022); [35] (Duque Monsalve et al., 2024); [36] (Rahmayanti and Rukmana, 2024); [37] (Shafique et al., 2024); [38] (Zheng et al., 2024); [39] (Calle Müller and ElZomor, 2024); [40] (Perrucci and Baroud, 2020); [41] (Zokaee et al., 2021); [42] (Di Giovanni and Chelleri, 2019); [43] (Mas et al., 2018).*

Assessment of Risks

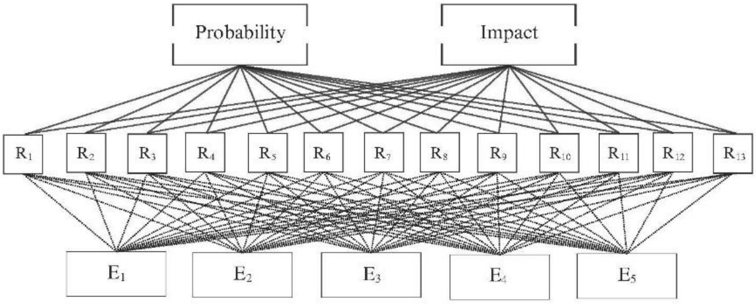
Probability and Impact Matrix (PIM)

Risk assessment is crucial in avoiding adverse outcomes, facilitating decision-making, and optimizing resource utilization. Risks are evaluated using risk scales. Risk scales evaluate a risk's amount, probability, and consequences and are frequently employed to study hazards in a specific project or context systematically (Aven, 2008). Among various tools, such as Failure Mode and Effects Analysis (*FMEA*) (Gupta & Thakkar, 2018; Sadeghi, Fayek, &

Pedrycz, 2010), Bowtie Analysis, and Risk Scoring System (Iqbal et. al, 2015; Klemetti, 2006; Li et. al, 2013; Raftery, 2003; Szymański, 2017; Wang, Zhan, & Cheng, 2020), the Probability and Impact Matrix *(PIM)* (Schieg, 2006) stands out due to its accessibility, simplicity, and systematic applicability across diverse fields (Hutchins, 2018; Renn, 2017).

In this study, risk assessment was performed using the Probability and Impact Matrix *(PIM)*. Thirteen risk factors were evaluated by five selected experts based on probability and impact criteria, using a Likert scale from 1 (lowest) to 7 (highest) (Dishar & Altaie, 2022; Hayat, 2017). The Probability and Impact Matrix (PIM) is a widely used tool for evaluating risks by combining the likelihood of occurrence with the potential severity of consequences. Each identified risk factor is assessed separately for probability and impact, typically using a Likert scale, and the two scores are multiplied to generate a composite risk value. This approach enables risks to be systematically compared and prioritized, ensuring that the most critical threats receive greater attention in planning and decision-making. In this study, thirteen risk factors related to post-disaster temporary housing units (PDTHUs) were scored by experts according to probability and impact, and their distribution within the matrix is illustrated in Figure 2.

Figure 2. *The hierarchical structure of the risk-scoring*



Reference: This figure was created by the authors.

To conduct the risk assessment, a group of five experts was engaged, representing both engineering and architectural backgrounds. As summarized in Table 2, the panel consisted of three civil engineers (a technical office engineer with 10 years of experience, a control engineer with 5 years of experience, and a site supervisor with 11 years of experience) and two architects (a design office architect with 8 years of experience and a technical office architect with 9 years of experience). All experts held a bachelor's degree in their respective fields and had professional experience directly related to construction and project management. Their role was limited to evaluating the thirteen risk factors identified through the systematic literature review. Using a seven-point Likert scale, they assessed each factor in terms of probability and impact. This approach ensured that while the risk identification process remained objective and literature-driven, the evaluation phase incorporated practical insights and professional judgment from experienced practitioners in architecture and civil engineering.

Table 2. Details about experts who participate in surveys

Expert ID	Personal Profession	Years of Experience	Education
E1	Technical Office Engineer	10	Civil Engineer
E2	Control Engineer	5	Civil Engineer
E3	Site Supervisor	11	Civil Engineer
E4	Design Office Architect	8	Architect
E5	Technical Office Architect	9	Architect

Entropy based- TOPSIS method

The TOPSIS method was developed by Hwang and Yoon (1981), has been widely applied across various fields, and has recently garnered significant attention from scholars and professionals. It is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). In the TOPSIS process, the performance ratings and the criteria weights are provided as crisp values.

Baykasoğlu et al. (2013) applied TOPSIS to address the vehicle selection problem in a Turkish land transportation company. Maghsoodi and Khalilzadeh (2018) used TOPSIS to evaluate the ranking of essential success factors in Iranian construction projects. Memari et al. (2019) utilized TOPSIS to identify sustainable suppliers based on nine criteria and thirty sub-criteria. Malakouti et al. (2019) employed TOPSIS to assess the adaptability of components to enhance housing quality. Zubayer et al. (2019) used TOPSIS to rank supply chain risks in Bangladesh's ceramic industry.

The extensive use of TOPSIS highlights its advantages: (1) straightforward calculation processes that can easily be translated into a spreadsheet, (2) scalar values that include both optimal and suboptimal alternatives, and (3) a logical representation of human perceptions of uncertainty.

Results

The TOPSIS method ranks alternatives by calculating their distances to the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS), which represent the most and least favorable outcomes, respectively (Zyoud, Kaufmann, Shaheen, Samhan, & Fuchs-Hanusch, 2016). Requiring at least two alternatives, TOPSIS is widely used due to its simplicity, ease of implementation, and intuitive interpretation, compared to other MCDM techniques.

Ranking risks

This section is organized under subheadings. The following section outlines the key algorithmic steps of the TOPSIS method in a structured manner.

a. Construction of the Decision Matrix

The initial step in the TOPSIS method involves constructing a decision matrix, which is the foundation for subsequent computations. The decision matrix D is an “n x m” matrix constructed by the decision maker after defining the alternatives and evaluation criteria. The rows of the decision matrix represent the decision alternatives, while the columns correspond to the evaluation metrics.

Formally, represents i=1, 2, ..., n denotes the alternatives, and j=1,2,...,m represents the criteria, where “d_{ij}” signifies the performance score of alternative ‘i’ concerning criterion ‘j’ (1).

The Likert Scale is commonly utilized in the TOPSIS approach due to its structured ordinal nature, which facilitates capturing nuanced expert judgments and ensures consistency in risk assessment procedures (Likert, 1932; Tzeng & Jih-Jeng, 2011). A 1 to 7 Likert scale provides an optimal balance between granularity and cognitive load, allowing respondents to express their assessments with sufficient differentiation. While a broader scale (e.g., 1-10) may introduce increased ambiguity and response bias, a narrower scale (e.g., 1-5) might limit the ability to capture nuanced judgments, reducing the overall reliability of the assessment (Miller, 1956).

Experts assessed the identified risks using a 1 to 7 Likert scale. The 7-point Likert scale was preferred as it overcomes the limited discriminative capacity of the 5-point scale while avoiding the excessive cognitive load associated with the 10-point scale. Thus, it provides sufficient granularity while enabling respondents to express their evaluations in a more consistent and reliable manner. The generating the initial decision matrix forms the basis for the subsequent TOPSIS computations (1).

$$D=\begin{bmatrix} d_{11} & d_{12} & \dots & d_{1m} \\ d_{22} & d_{22} & \dots & d_{2m} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ d_{n1} & d_{n2} & \dots & d_{nm} \end{bmatrix} \quad (1)$$

b. Normalization of the Decision Matrix

In stage 2, each criterion in the decision matrix undergoes normalization. The normalization process adjusts the values of the decision matrix to fall within a standardized range—typically between zero and one—allowing for accurate performance comparisons among alternatives. Each a_{ij} value is normalized by dividing it by the square root of the sum of the column in which it appears, as shown in Equation 1. This process results in the normalized decision matrix *R*, where each element represents a relative performance score adjusted for comparability across different criteria.

Equation 1:

$$R_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}2}}$$

For j=1,2,…,n, where m is the number of rows and n is the number of columns (2).

$$R_{ij}=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{22} & r_{22} & \cdots & r_{2m} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \qquad (2)$$

c. Weighting and Standardization of the Decision Matrix via the Entropy Method

At this stage, a weighted, standardized decision matrix is constructed to enhance the accuracy of risk prioritization. First, the weight values of the evaluation criteria (w_i, i=1, 2,…,m) are computed using Equation 2. These weights reflect the relative importance of each criterion in the decision-making process.

The Entropy Method is employed in this study to determine the weight of each criterion in the TOPSIS decision-making process. The Entropy method quantifies the informational entropy of each criterion and assigns greater weight to criteria exhibiting higher variability, as they contribute more to the decision-making process (X. Wang et al., 2020). The entropy scores for each criterion (e_{ij}) were computed using Equation 2, providing a quantitative measure of their contribution to the decision-making process.

Equation 2:

$$e_{ij} = -\frac{1}{\ln(m)}\sum_{i=1}^{m} r_{ij}\, ln(r_{ij})$$

The weights obtained by using the Entropy method. The differentiation power of the alternatives for each criterion (d_j) is obtained by subtracting the Entropy value from 1 (Equation 3). In this case, for criteria with high e_j, d_j will be low because the information uncertainty or similarity between alternatives is high. On the other hand, if e_j is low, d_j will be high, indicating that the relevant criterion provides intense discrimination in the decision process. In TOPSIS applications, criterion weights are usually determined by Equation 4 in proportion to their d_j values.

Equation 3:

$$d_j = 1 - e_j$$

Equation 4:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$$

The weighted standardized decision matrix V is obtained by multiplying the calculated weights by each element of the normalized decision matrix R (3). The weights were calculated according to Equation 4.

m=13, ln(13)=2.56, and 1/ln(13)=0.39; the values obtained are shown together in Table 3.

Table 3. *Entropy Weight*

Equations		1	2	3	4	5
Equation 2:	$e_{ij} = -\frac{1}{\ln(m)}\sum_{i=1}^{m} r_{ij}\, ln(r_{ij})$	1.609	1.716	1.701	1.645	1.666
Equation 3:	$d_j=1-e_j$	-0.609	-0.716	-0.701	-0.645	-0.666
Equation 4:	$W_j=\frac{d_j}{\sum_{j=1}^{n} d_j}$	0.182	0.215	0.210	0.193	0.200

$$V=\begin{bmatrix} w_1r_{11} & w_2r_{12} & \dots & w_mr_{1m} \\ w_1r_{21} & w_2r_{22} & \dots & w_mr_{2m} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ w_1r_{n1} & w_2r_{n2} & \dots & w_nr_{nm} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & \dots & v_{1m} \\ v_{21} & v_{22} & \dots & v_{2m} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ v_{n1} & v_{n2} & \dots & v_{nm} \end{bmatrix} \quad (3)$$

d. Determining the Positive *and Negative Ideal Solutions*

At this stage, the Positive Ideal Solution (*PIS*) and Negative Ideal Solution (*NIS*) sets are derived from the weighted decision matrix *V*. Their determination depends on the nature of each evaluation criterion. For beneficial (positive) criteria, the *PIS* set consists of the highest values in each column of the *V* matrix, whereas the *NIS* set consists of the lowest values. Conversely, for non-beneficial (negative) criteria, the *PIS* set consists of the smallest values, while the *NIS* set includes the highest values. Mathematically, these solutions are expressed as follows:

$V^* = \{v_1^*, v_2^*,\dots,v_m^*\}$ where $v_j^* = \max v_{ij}$ for beneficial criteria, minvij for non-beneficial criteria.

$V^- = \{v_1^-, v_2^-,\dots,v_m^-\}$ where $v_j^- = \min v_{ij}$ for beneficial criteria, maxvij for non-beneficial criteria.

e. Computation of Distance Measures to the Positive and Negative Ideal Solutions

The Euclidean distances from each alternative to the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) are computed in this step. The Euclidean distance metric is employed to quantify the relative separation of each decision alternative from the PIS and NIS. For a standardized evaluation across criteria, the computed weights are applied to the normalized decision matrix, forming the weighted normalized decision matrix (V). Subsequently, the Euclidean distance values are calculated using Equation (5) for the PIS and Equation (6) for the NIS.

For each decision alternative i=1, 2, …, n, the Euclidean distance is computed as follows:

$Equation\ 5: S_i^*: \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_j^*\right)^2}$ where Si^* represents the distance to the PIS.

$Equation\ 6: S_i^-: \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_j^-\right)^2}$ where Si^- represents the distance to the NIS.

PIS and NIS values are shown in Table 4.

Table 4. *PIS and NIS Values*

Values	1	2	3	4	5
NIS	0.017	0,.030	0.099	0.077	0.081
PIS	0.087	0.084	0.016	0.015	0.017

f. Computation of Closeness Coefficients (CC) to the Ideal Solution

At this stage, the distances to the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) serve as the basis for computing the Closeness Coefficient (CC) for each decision alternative. Equation (7) provides the mathematical formulation for computing each decision alternative's Closeness Coefficient (CC).

Accordingly, decision alternatives with C_i^* values approaching one are more favorable. For each decision alternative (i=1, 2, …, n), the Closeness Coefficient (C_i^*) satisfies the following condition:

$$0 \leq C_i^* \leq 1$$

Mathematically, the Closeness Coefficient (C_i^*) for each decision alternative is computed as follows:

$$Equation\ 7: C_i^* = \frac{S_i^-}{S_i^* + S_i^-}$$

where:

- S_i^* represents the Euclidean distance from the Positive Ideal Solution (PIS), and
- S_i^- represents the Euclidean distance from the Negative Ideal Solution (NIS).

This study prioritizes the risks identified through the *SLR* and structured interviews using the *TOPSIS* approach based on their *CC* values. In the *TOPSIS* framework, an alternative is considered more favorable as its *CC* value approaches 1, meaning it is closer to the *PIS* (S_i^*) and farther from the *NIS* (S_i^-). Therefore, utilizing the *CC* makes it possible to determine the ranking order of all alternatives and select the most suitable option from a set of feasible alternatives. Higher *CC* values indicate a greater priority assigned to the corresponding risk.

Table 5 presents the S_i^*, S_i^-, and *CC* values alongside the corresponding risk rankings identified in this study. R_3, R_4, and R_5 are the top three risks that should be prioritized in site selection and infrastructure planning for *PDTHUs*. The findings will be further analyzed in the subsequent discussion section.

__Table 5.__ Rank of Risk Factors

Risk ID	S_i^*	S_i^-	CC Values	Rank
R_1	0.0963	0.0864	0.4729	9
R_2	0.0843	0.0841	0.4995	5
R_3	0.0741	0.0906	0.5501	3
R_4	0.0568	0.1080	0.6554	1
R_5	0.0805	0.1037	0.5631	2
R_6	0.0910	0.0837	0.4792	7
R_7	0.1015	0.0839	0.4526	10
R_8	0.1072	0.0814	0.4314	11
R_9	0.0784	0.0810	0.5083	4
R_{10}	0.0876	0.0796	0.4760	8
R_{11}	0.0845	0.0843	0.4993	6
R_{12}	0.1275	0.0313	0.1972	13
R_{13}	0.1010	0.0633	0.3854	12

Discussion

Inadequate site selection and infrastructure planning have severely affected disaster-stricken communities. Events such as the 1999 Gölcük and 2023 Pazarcık-Elbistan earthquakes demonstrated critical shortcomings in identifying suitable land and preparing infrastructure for temporary housing (Karabacak et al., 2023; Tas, Tas, & Cosgun, 2010).

R3:Temporary housing areas are not suitable for expansion in case of need

The inability to expand temporary housing after disasters threatens long-term recovery by causing overcrowding and resource shortages. Fayazi et al. (2019) noted poor camp conditions after the Bam earthquake hindered reconstruction, while Celentano et al. (2019) found limited expansion in Central Italy undermined sustainability. Ghomi et al. (2021) further stressed that non-adaptable infrastructure delays recovery. These findings underscore the need for long-term planning in site selection, ensuring housing can accommodate population growth. Modular, easily expandable units, supported by trained emergency teams and clear allocation plans, are essential for scalable post-disaster housing.

R5: The location of the temporary houses to be built is far away from the existing housing areas

The placement of temporary housing far from residential areas creates socio-economic and psychological challenges. Displaced individuals face weakened social networks, reduced service access, and prolonged distress. Rzepka et al. (2022) note that isolation harms mental health, while Johnson (2007) stresses the role of social connections in recovery. After the Bam earthquake, prefabricated housing in remote areas disrupted community cohesion and socio-economic ties (Fayazi & Lizarralde, 2013). Afkhamiaghda et al. (2021) highlight the need to integrate spatial sustainability and social interaction in site selection. Thus, locating temporary housing near existing settlements supports social structures and urban reconstruction (Pezzica et al., 2022). Support teams and community activities should further strengthen education, health, and social interaction in these areas.

R4:Lack of pre-determined land for temporary housing - Difficulty in finding land

The absence of pre-designated land for temporary housing poses major challenges in post-disaster management, leading to logistical delays, overlooked vulnerabilities, and planning inefficiencies. Effective shelter implementation requires pre-identified sites that meet regulations and minimize infrastructure risks. Hosseini et al. (2016b, 2020, 2021) developed models for sustainable and optimal site selection across several countries, while Iuchi (2014) showed that resettlement planning varies by community characteristics. Dayanır et al. (2022) stress defining clear selection criteria, and in Turkey, AFAD coordinates this process under 2015 guidelines. To strengthen preparedness, “emergency settlement areas” should be legislatively established before disasters, supported by updated digital risk mapping, and communicated to residents through training and awareness programs.

Conclusion

The frequency of natural disasters has increased in recent years due to climate change, unplanned urbanization, and uncontrolled population growth (Félix et al., 2015; Pezzica et. al, 2022). Among natural disasters, earthquakes have caused the most substantial damage in terms of both scale and severity (Liu et. al, 2020; Sengar et al., 2013). Ensuring adequate shelter is necessary for disaster victims (George et al., 2023). The need for accommodation in disaster-affected areas is typically managed in three phases: the emergency relief phase, which involves using tents; the recovery phase, which includes temporary housing units; and the rehabilitation phase, which focuses on permanent housing solutions (Savasır, 2008). The recovery phase, particularly, is critical for the construction sector, as it demands careful planning, organization, and technical expertise.

This study analyzed the critical factors influencing temporary housing solutions, focusing on site selection and infrastructure requirements. A systematic literature review identified key risks associated with these factors, which were subsequently validated through expert consultations. The study employed entropy-based TOPSIS methodologies to prioritize risks, providing a structured framework for risk prioritization in disaster recovery planning. This framework has provided practical and conceptual implications for policymakers and practitioners in this field.

Practical implication

The proposed methodology equips policymakers and practitioners with a systematic decision-making tool for identifying and prioritizing strategic risks in PDTHUs planning. The study contributes to the development of more resilient, informed, and efficient temporary housing solutions by addressing critical site selection and infrastructure-related hazards. The findings also support the importance of enhanced coordination in land allocation, the proximity of housing units, and the adaptability of shelter designs.

The novelty of this study lies in its integration of a systematic literature review, expert validation, and advanced decision-making techniques. Its emphasis on site selection and infrastructure requirements sheds light on critical yet frequently overlooked dimensions of post-disaster planning. This dual focus offers a comprehensive framework for policy-making and disaster risk management practices. The results underline the need for a national-level "Disaster Risk Management and Shelter Strategy" emphasizing pre-disaster preparedness and prioritizing identified risks for more effective planning and response.

Conceptual implication

This study combines a systematic literature review with expert validation and a quantitative MCDM approach (Entropy-based TOPSIS) to address strategic risks in PDTHUs planning. It offers a reproducible and scalable framework for disaster-prone regions, aiming to enhance the effectiveness of post-disaster housing responses. The research enriches academic literature and policy development by bridging theoretical insights with practical implementation.

By emphasizing risk prioritization during the temporary housing planning phase, the study fills a critical gap in disaster management literature, where site selection and infrastructure considerations are often overlooked. The integrated methodology illustrates how qualitative expert judgments can be systematically transformed into data-driven decisions. This contributes to advancing interdisciplinary frameworks integrating construction management, disaster resilience, and decision sciences. As such, the study lays a conceptual foundation for future research to operationalize strategic planning in post-disaster shelter solutions.

Limitations and Future Work

This study's limitations include site selection and infrastructure risks encountered in post-disaster temporary housing units. However, the topic of PDTHUs extends beyond these issues, encompassing a much broader range of risk topics. Future studies should focus on sub-categories such as utilization, sustainability, and design risks related to PDTHUs.

This study was conducted using the Scopus database. Future research could include Web of Science, Google Scholar, or a combination of these databases. Additionally, structured interviews were employed in this study, and the limited number of expert interviews restricts the research's scope and risk assessment. Future studies could be conducted with larger sample groups and utilize different data collection tools such as semi-structured interviews and/or questionnaires. Nevertheless, the approach taken in this study is adaptable for further applications. The results contribute to the academic literature on post-disaster housing by offering a systematic and empirical methodology for risk prioritization. Future research should utilize tools such as Geographic Information Systems (GIS) to enhance planning techniques and strive to increase stakeholder engagement and participation.

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CHAPTER 11

AN ANALYSIS OF TURKIYE'S DECARBONISATION PROCESS IN BUILDINGS

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Introduction

In the early 19th century, the rise in population, consumption, and human demands reached a point at which the natural environment could no longer sustain itself. This resulted in an imbalance between production and consumption, which led to the disruption of the world's natural equilibrium. Following the escalation of the problem to a scale that had an impact on humanity, environmental organisations were established with the aim of advocating for measures to be taken against environmental problems. Examples of such organisations include the Council for the Protection of Rural England, the National Wildlife Federation, the World Wildlife Fund for Nature, and Greenpeace. In 1968, the Club of Rome, an unofficial organisation, examined issues such as environmental pollution and degradation, industrial production,

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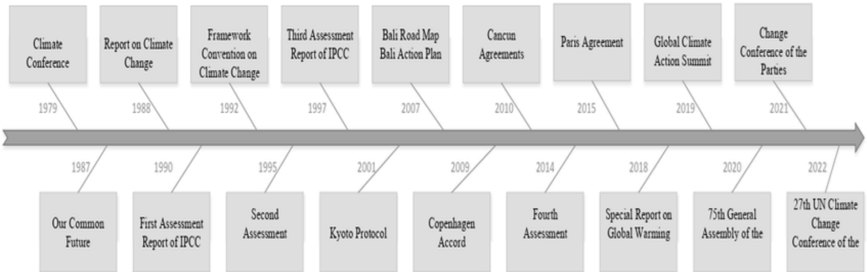
population, agricultural production, and natural resources through the Project on Problems Threatening Humanity. The study was published in 1972 under the title The Limits to Growth. This initiative gave rise to the concept of sustainability, which aims to utilise natural resources in a manner that ensures the benefits thereof are available to future generations. The concept first entered the international arena in 1987 with the publication of Our Common Future, also known as the Brundtland Report. This report was prepared by the United Nations World Commission on Environment and Development, and it proposed a strategy for addressing the problems of environmental assets and economic growth (Brundtland, 1987). Concurrent with these developments, the ecological crisis began to gain more prominence, and the issue of climate change, which is the root cause of the ecological crisis, gained importance.

The primary cause of climate change, which in turn triggers the ecological crisis, is the production of greenhouse gases resulting from population growth, industrialisation, and increased use of fossil fuels. The presence of greenhouse gases in the atmosphere leads to an increase in the thickness of the layer surrounding the Earth, thereby preventing heat from escaping. This results in the trapping of heat on the Earth's surface, which is known as the greenhouse effect. These factors are causing a shift in global climate, manifesting in rising global temperatures. The Intergovernmental Panel on Climate Change (IPCC) has predicted that if greenhouse gas emissions continue to increase throughout the 21st century, the global average surface temperature will rise by 3.3-5.7 °C by 2100 compared to the average value between 1850 and 1900. This increase would cause significant social, economic, and ecological damage. In the context of human well-being, it is imperative to expedite endeavours to curtail greenhouse gas emissions, with the objective of constraining global warming to below 2 °C (Liang Y. et al., 2023).

The fact that carbon dioxide, a dominant greenhouse gas, is closely linked to human activities and the need to reduce the impact of these activities on climate change has given rise to the concept of decarbonisation, which refers to the process of reducing or eliminating carbon emissions.

The initial measures directed towards environmental preservation, encompassing indirect decarbonisation targets, were initiated in 1972 during the United Nations Conference on the Human Environment (Stockholm Conference) in Stockholm, with the establishment of the United Nations Declaration on the Human Environment. In the aftermath of the 1992 Rio Conference (United Nations Conference on Environment and Development), the United Nations Framework Convention on Climate Change (UNFCCC) and Agenda 21 were adopted, thus facilitating public participation (Ebbesson, J., 2022; Morin, J. F. et al., 2024). The Kyoto Protocol, which was adopted in 1997, established legally binding targets for reducing greenhouse gas emissions (San Cristóbal, J. R., 2010). The Paris Agreement, which was signed in 2015, adopted the objective of maintaining the global average temperature increase below 2°C above pre-industrial levels and limiting the temperature increase to 1.5°C (Rajbhandari, S. and Limmeechokchai, B., 2021). In accordance with these objectives, the primary strategy has been identified as decarbonisation. Figure 1 presents a chronology of global climate change actions.

Figure 1 Chronological overview of global climate change actions



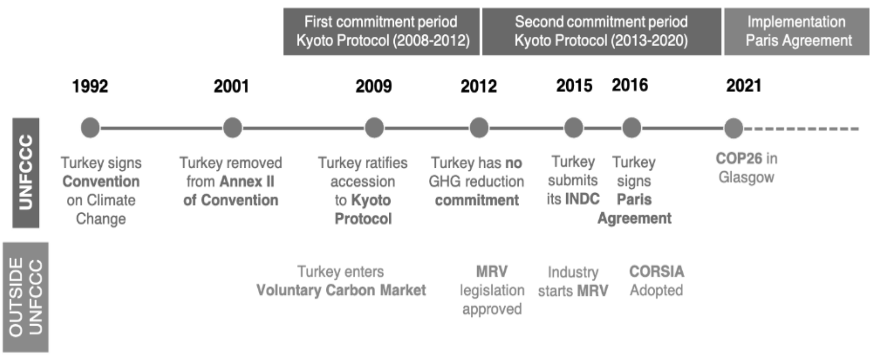
Reference: Ran, 2023

The IPCC published its Sixth Assessment Report (AR6), titled Climate Change 2023, in 2023. The report provides a comprehensive overview of the current state of climate change, its projected short- and long-term consequences, and proposed short-term action plans to adapt to these consequences. As stated in AR6, the present circumstances and extant policies render it challenging to maintain temperatures below 2°C and to avert them from exceeding 1.5°C in the 21st century. It is evident that a considerable proportion of climate-related risks exceed those evaluated in AR5, and the projected long-term impacts are found to be severalfold higher than those currently observed. Despite the implementation of rapid and sustained reductions in greenhouse gas emissions, it will require approximately twenty years to achieve a noticeable slowdown in global warming, and several years to observe significant changes in atmospheric composition. To limit human-induced global warming, it is imperative that net zero CO_2 emissions are achieved. It is imperative to acknowledge that, in the absence of achieving net zero CO_2 emissions, the extent of cumulative carbon emissions and the level of greenhouse gas emission reductions over the present decade will play a pivotal role in determining the capacity to restrict warming to 1.5°C or 2°C. It is estimated that the CO_2 emissions from existing fossil fuel infrastructure will exceed the remaining carbon budget for 1.5°C without additional reductions. To limit warming to 1.5-2°C, it is imperative that rapid reductions in greenhouse gas emissions occur across all sectors within this decade. Should this limit be exceeded, it will be necessary for net negative CO_2 emissions to be implemented to enable a reversal, a process which will give rise to further implementation and sustainability concerns. The failure to implement mitigation and adaptation measures in a timely manner can result in the entrenchment of high-emission infrastructure, the escalation of risks associated with regional abandonment, and the augmentation of costs. This, in turn, can lead to a diminution in the feasibility of projects and an escalation in losses and damage (IPCC). Consequently, the identified measures must be implemented expeditiously, with the support of governments and policies. In this context, the present study aims to examine the work done in this field, specifically in Türkiye's construction sector, to emphasise the importance of decarbonisation. In the first stage of the research, the practices of different countries worldwide were examined through a literature review. Subsequently, the research was narrowed to focus on the construction sector in Türkiye, and conclusions were drawn. In conclusion, the investigation revealed certain deficiencies, and a series of recommendations was formulated.

The Decarbonisation Process in Türkiye

Efforts are being made to prevent the ecological crisis caused by rapidly increasing population, growing fossil fuel consumption, the rise in atmospheric temperatures due to greenhouse gases emitted from fossil fuels, and the resulting climate change, depletion of non-renewable resources, and loss of biodiversity through sustainable solutions. When examining the historical process of these efforts specifically in Türkiye, it can be seen that they began with the adoption of the UN (United Nations) Declaration on the Human Environment at the UN Conference on the Human Environment (Stockholm Conference) held in Stockholm in 1972. The process continued with Türkiye's participation in the UN Conference on Environment and Development (Rio Summit) held in Rio de Janeiro in 1992. At this conference, Agenda 21, an action plan, was adopted, and Türkiye re-evaluated its environmental policies. The Rio Conference was followed by the World Summit on Sustainable Development in Johannesburg in 2002, which aimed to follow up on the goals discussed at the Rio Conference and adopted by governments at the UN Millennium Summit in 2000. In 2009, Türkiye became a party to the Kyoto Protocol through the Copenhagen Agreement and, with its signing of the Paris Climate Agreement in 2021, established its sustainable development and decarbonisation targets as an official party to the Paris Agreement (Kat B. et al., 2024; Olçum, G. A., and Yeldan, E., 2013; Ministry of Foreign Affairs of the Republic of Türkiye). Figure 2 provides a comprehensive chronology of the evolution of climate policy developments in Turkiye.

Figure 2 Chronology of climate policy developments in Türkiye



Reference: EBRD,2025

These targets include a 41% reduction in greenhouse gas emissions by 2030 and achieving net-zero emissions by 2053. In accordance with Türkiye's Climate Change Mitigation Strategy and Action Plan, which is scheduled for implementation between 2024 and 2030 by the Ministry of Environment and Urbanisation, the establishment of an Emissions Trading System is to be pursued as a carbon pricing instrument, entailing the imposition of an upper limit on greenhouse gas emissions. A roadmap is to be formulated for the capture, utilisation, and evaluation of carbon with a view to reducing unavoidable greenhouse gas emissions. Moreover, the Ministry of Environment and Urbanisation will assume responsibility for the regulation of procedures and principles pertaining to the reporting and verification of greenhouse gas emissions from human activities, including but not limited to excessive use of fossil fuels, land use changes, and deforestation. Additionally, the ministry will be responsible for the monitoring of greenhouse gas emissions from the production of construction products. The reporting and verification procedures and principles to be implemented by the Ministry of Environment and Urbanisation will include the promotion of the use of green cements with lower carbon emissions and lower clinker content. Furthermore, the ministry will create databases in relevant sectors to increase energy efficiency in buildings in selected pilot cities/regions and conduct analyses to determine the overall impact. In addition to the aforementioned, the Ministry of Environment, Urbanisation, and Climate Change will establish activities that will assist carbon reduction efforts in the industrial, agricultural-cultural, and land use sectors, in addition to the building sector.

Since the early 2000s, Türkiye has been implementing measures to reduce carbon emissions. However, factors such as the energy sector's reliance on fossil fuels, inadequate transport infrastructure, high emissions in the industrial sector, financial constraints, and a paucity of policy and legal regulations have impeded progress. As the examination of this process and the emphasis placed upon its significance is of considerable importance, this study conducted a literature review with a focus on nZEB (nearly zero-energy buildings) to investigate decarbonisation practices in Türkiye and around the world. The data obtained was then utilised to facilitate a comparative analysis of practices in Türkiye and across the globe. This analysis yielded specific recommendations for Türkiye.

Decarbonisation Practices Around the World

Decarbonisation practices around the world are shaped by various legal frameworks according to local characteristics such as the environmental goals of different countries or regions, their vulnerability to climate change based on their location, their economic structures, their level of development, and their energy policies. This section examines the decarbonisation policies and practices of the United States, China, and Europe, specifically within the construction sector, in line with the study's objectives.

United States

One of the most significant steps taken by the United States in the field of clean energy and climate change is the Inflation Reduction Act, which came into force in 2022. This law aims to increase the use of clean energy technologies, mitigate the effects of climate change, and enhance resilience, providing incentives for renewable energy projects to support these goals (The White House). Another important step is the Clean Air Act. This act came into force in 1963, and with the 1970 amendment, national air quality standards (NAAQS) were established, and the federal government was given powers to improve air quality. The 1990 amendment introduced significant changes in areas such as the control of acid rain and air pollutants and the protection of the ozone layer (EPA-1, EPA-2). In 2021, the United States rejoined the Paris Climate Agreement and is working towards global cooperation in line with its neutrality goals.

Despite the implementation of specific legal provisions by the US government, a greater volume of studies has been conducted within the academic domain. For instance, a study was conducted to examine the balance between operational and embodied carbon in

30 buildings in California, using life cycle greenhouse gas emissions as a metric. The findings indicated that embodied carbon levels surpassed those of operational carbon, with the latter being predominantly influenced by the energy source (electricity and natural gas). Additionally, the consequences of embodied carbon were observed to be more pronounced than those of operational carbon in fully electric buildings. In the case of electric/gas buildings, the impacts of operational carbon exceeded those of embodied carbon in 9 out of 11 buildings. This demonstrated that a shift away from fossil energy sources could result in substantial decarbonisation for new construction projects in California (Benke B., 2024). A further study conducted an examination of the impact of the implementation of various building performance standards for commercial buildings in the US from 2024 to 2050. The study considered policies such as greenhouse gas emission targets and peak grid load flexibility. This is defined as the ability to reduce energy use or shift demand to different times during periods of peak demand on the electricity grid. When both standards were applied in combination, an 89% decrease in carbon emissions was observed, thereby reaching a level that exceeded the targeted 80% carbon reduction by 2050. This finding underscores the significance of integrated methodologies for the management of energy consumption and emissions in buildings (Andrews, A. and Jain, R.K., 2023). The present study examines the impact of policies aimed at reducing greenhouse gas (GHG) emissions from buildings in Seattle, Washington. The study emphasises that cities need to focus on reducing emissions from their existing building stock in order to meet their emission targets. The Seattle building stock was modelled using benchmarking and building characteristics data, and the effects of various policies implemented in commercial and multi-family buildings were evaluated. The study's key findings indicate that the proposed policy could reduce cumulative emissions by 19 % between 2020 and 2050. Furthermore, it is suggested that a five-year

delay in implementing the policy could limit this reduction to 12 %. Finally, it is proposed that including smaller buildings in the policies could increase savings to 34 % Moreover, the study discusses the potential application of these results to other cities. The study emphasises the necessity of incorporating critical factors such as timing, building type, and size when formulating emission reduction policies for urban areas (Walter, T. and Mathew, P., 2021).

China

China is the world's largest emitter of greenhouse gases and has established comprehensive plans and legal frameworks with the aim of reducing this. The Renewable Energy Law, which came into force in 2006, has provided a purchase guarantee for renewable energy production and created a framework to accelerate the transition to clean energy. Following the amendment to the law in 2009, the efficiency of renewable energy, otherwise termed the capacity factor, has been increased (Akbal F.H., 2022). In 2013, China implemented the Emissions Trading System (ETS), a market-based instrument that has the potential to reduce global greenhouse gas emissions by regulating resources across businesses, industries, and regions to reduce emissions at a lower total cost, on a pilot basis in seven regions within the energy sector. In 2021, China expanded the ETS and initiated its implementation on a national scale within the electricity sector. The aforementioned measures are intended to ensure that China halts carbon emission increases by 2030, reaches peak emissions, and then reduces emissions. The objective is to achieve the 2030 Carbon Peak Target and the 2060 Carbon Neutrality Target (Wang B. and Duan M., 2025).

In addition to these government initiatives aimed at decarbonisation, numerous academic studies have also been conducted. The extant literature has examined various parameters affecting carbon emissions, compared certain parameters, made predictions about the future state of emissions, and provided recommendations. For instance, the future status of carbon emissions from buildings on an urban scale in China was examined, and it was determined that more than 80% of urban carbon emissions originate from the heating and electricity sectors. To reduce this, the recommendation was made that heating should be done with non-fossil energy sources and that electricity should be produced using renewable energy sources. Projections indicate that this could result in a decline of up to 78% by the year 2060 compared to the year 2020 (Wei C. et al., 2023). In another study investigating the factors affecting carbon emissions in China and the US, the order of importance of the criteria affecting emissions in China was determined to be, from largest to smallest: per capita GDP (Gross Domestic Product), population, natural gas, energy intensity, coal and oil, while in the US they were found to be, in order, population, energy intensity, per capita GDP, oil, natural gas and coal (Jiang X.T. et al., 2018). A further study undertaken in Hong Kong investigated alterations in embedded carbon emissions in high-rise buildings, with the parameters of design and material usage being given consideration. The findings, based on a comparison of structural forms and building heights, indicate that steel structures exhibit 25-30 % higher embodied carbon emissions compared to composite and reinforced concrete alternatives. It has been demonstrated that utilising 80 % of recycled steel in construction results in a reduction of embodied carbon emissions by approximately 60 %. Furthermore, it was concluded that as building height increases, the embedded carbon per floor area decreases but begins to increase after a certain point; in other words, there is an optimal height range for each building type or structural form (Gan V.J. et al. 2017).

A study was conducted in order to compare energy consumption and emissions in high-rise and low-rise buildings (including buildings, transport, and infrastructure) in downtown Chicago. The study found that the high-rise area generated approximately 25% more life-cycle energy per person per year than the low-rise area. Furthermore, it was observed that the largest share of total energy was accounted for by building operational energy use, followed by transport as the second largest share (Du P. et al., 2015). A further review article was published, which evaluated the embodied carbon and energy outcomes of building materials between 1981 and 2019. The study also identified the most commonly used materials by country. The findings of the research indicate that concrete is the material that has been most extensively studied, with steel ranking second in terms of the volume of research activity. The terms "recyclability" and "recycling" were found to be used more frequently in relation to steel and concrete, indicating a general concern about their environmental impacts. A significant number of recent studies have investigated the potential of geopolymer concrete as a novel material for the reduction of carbon emissions. Research on earth materials and masonry (the assembly of materials such as stone, brick, and concrete blocks using mortar in construction) is being conducted by developing countries, particularly India. Meanwhile, China, the leading cement producer, is conducting research on concrete and steel. In certain European countries, including Norway, Slovenia and Estonia, there has been a more pronounced focus on research in this area. It is a matter of some surprise that wood has a higher embodied energy than the materials previously mentioned, with steel in fact having the highest embodied energy of all. Conversely, earth materials and wood have been found to have the lowest embodied carbon ratios (Cabeza, L. F. et al., 2021).

European Union

The European Union (EU) has a more advanced legislative framework, regulations, and systems in place for decarbonisation measures than other countries. As with China, the EU has also implemented an emissions trading system, albeit one that was initiated in 2005 and has since undergone significant development and maturation. The EU Emissions Trading Scheme (EU ETS) encompasses not only the energy and transport sectors, but also numerous other sectors, including industry and aviation. The primary objective of the ETS is to impose limitations on the number of CO_2 emission allowances allocated, and to subsequently sell these to organisations that generate relevant emissions. The establishment of a secondary market for CO_2 is initiated through the trade of these organisations. In circumstances where the financial burden of CO_2 emission allowances is substantial, some industrial facilities may find it more cost-effective to implement energy efficiency initiatives or transition to alternative fuels with lower emissions rather than to continue incurring the expense of allowances (Lovcha Y. et al., 2022). This approach is conducive to enhancing energy efficiency, thereby facilitating substantial progress in reducing emissions.

Other significant developments in this area include the entry into force of the first European Union Renewable Energy Directive (RED) in 2009, the Renewable Energy Directive (RED II) in 2018, which aims to increase the share of renewable energy to 32% by 2030 compared to 1990 levels, and the restructuring of the European Union Emissions Trading System (EU ETS) to reduce greenhouse gas emissions by at least 40 % by 2030, and the introduction of the European Green Deal in 2019, which aims to achieve climate neutrality by 2050. In this regard, the European Climate Law, which aims to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels, was adopted in 2020 to establish a legal framework (Kougias I. et al., 2021).

In addition to the legal measures implemented by governments for decarbonisation, numerous academic studies have examined carbon emission values during production and operation phases, forecasting changes in these values under various parameters based on the anticipated impacts of future climate change. Examples of such studies include: A study conducted in Belgium examined the operational phase in the life cycle assessment (LCA) of an office building, considering future climate data and changes in the energy system. The study found that climate change effects would lead to an 18% decrease in heating but a 32.4% increase in electricity use for cooling and ventilation, thus increasing total energy consumption. The study emphasised the importance of considering climate change when examining building energy consumption (Ramon D. et al., 2023). The study, which sought to evaluate the range of embedded carbon emissions in residential buildings by examining them through 95 case studies and analysing the issues that prevent comparing cases, found that embedded carbon emissions in residential buildings ranged from 179.3 $kgCO_2e/m^2$ to 1050 $kgCO_2e/m^2$, while emissions during the operational phase ranged from 156 $kgCO_2e/m^2$ to 4049.9 $kgCO_2e/m^2$. Furthermore, it has been determined that embedded carbon emissions vary between 9% and 80% of total carbon emissions, with the share of embedded emissions being 9-22% in conventional buildings, 32-38% in passive buildings, 21-57% in low-energy buildings, and 71% in nearly zero-energy buildings (nZEB) (Chastas P. et al., 2018).

A study was conducted to examine the embedded energy use and operational processes of buildings. The study found that embedded carbon emissions during the production phase can be reduced by optimising the building structure, improving material performance, and using bio-based materials. This reduction in consumption of carbon-intensive materials is a key finding of the study. Prefabrication technology has been demonstrated to play an effective role in decarbonising the building production process, as it accelerates the construction process. In the context of the building operational process, the implementation of solutions such as energy saving and transition to electricity-based systems, renewable energy integration, and smart energy management has been demonstrated to reduce carbon emissions (Liang Y. et al., 2023).

The Application of Decarbonisation in Different Sectors in Türkiye

A number of factors have contributed to the acceleration of decarbonisation measures in Türkiye, including the adoption of the Kyoto Protocol and the Paris Agreement. A significant economic impact on Türkiye is anticipated from the European Green Deal (EGD) initiated by the European Union (EU) in 2019. The objective of this agreement is to achieve the EU's goal of achieving carbon neutrality by 2050 and to reduce carbon emissions by 55 % by 2030 compared to 1990 levels. Given Türkiye's status as a pivotal partner in EU trade relations, the ramifications of the Green Deal are of paramount significance for Türkiye. In particular, the EU is set to implement the Carbon Border Adjustment Mechanism in 2026, a policy that will involve the imposition of a carbon tax on all products subject to import duties. Consequently, EU countries are expected to transition their export markets to countries that provide carbon-free technology, with the objective of decarbonising their economies and industries. The European Union has announced its intention to initiate a three-year transition period in 2023, with the objective of establishing the operational functionality of this mechanism (Mirici, M. E., and Berberoğlu, S., 2022).

Aşıcı et al. (2020) modelled the carbon cost for Turkish exports at the end of the transition period and predicted that if CO_2e (equivalent) emissions were paid per tonne for exports to the EU, this would result in a cost of €170 million for the cement sector alone. Consequently, a substantial carbon tax will be applied to exports from the cement industry, as well as from the electricity, automotive, iron and steel, machinery, textile, and agriculture sectors. In this context, the AYM has become not only an environmental sanction but also an economic sanction. In particular, the iron, steel, aluminium, cement, plastics, chemical and agriculture sectors will have to modify their production processes to ensure decarbonisation in the production process. Consequently, to prevent potential export losses in Türkiye, it is inevitable that the methods for calculating carbon emissions released during production processes become widespread and that the decarbonisation process is accelerated (Aşıcı et al., 2020; cited in Mirici, M. E., and Berberoğlu, S., 2022). In order to initiate this process, it is first necessary to ascertain the proportion of emissions attributable to each sector and thereafter establish targets for their reduction. A comprehensive literature review was conducted in this context.

It is estimated that emissions from Türkiye's energy sector account for approximately 70% of all emissions, thus representing the largest share. The emissions that are primarily responsible for the sector's carbon footprint are those that are produced as a consequence of the combustion of fossil fuels, such as coal, oil, and natural gas, for the purpose of generating heat and electricity. It is estimated that greenhouse gas emissions from the agricultural sector account for approximately 14% of total emissions, with origins including livestock and manure, synthetic fertiliser use, and urea applications. The emissions resulting from industrial processes and product utilisation are comparable to those originating from the agricultural sector, constituting approximately 12.7% of the country's aggregate emissions (Özdemir M. et al., 2024).

The utilisation of raw materials such as aluminium, iron, steel, plastic, cement, and paper in industrial applications gives rise to the emission of substantial quantities of greenhouse gases during the production process. As these applications account for 21% of global greenhouse gas emissions, ensuring emission efficiency in industrial production processes, decarbonising raw materials, and reducing material intensity and demand are important steps towards achieving decarbonisation on a global scale. In order to reduce carbon emissions in the industrial sector, the following measures are recommended: the energy-efficient use of lighting and heating systems in factories; the use of natural gas in place of coal for the operation of machinery; the use of scrap steel and aluminium in place of new aluminium smelting and steel forging; and the development of new policies for hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride, which reduce emissions and leaks from containers and equipment (Batur B. et al., 2023).

The proposals introduced to decarbonise the energy sector, which accounts for approximately 70% of all emissions in Türkiye, involve increasing electricity production instead of fossil fuels and doing so by increasing the installed capacity of renewable energy sources rather than hydroelectricity, which is negatively affected by drought and climate change (Işık M. et al., 2021). Moreover, Türkiye's Nationally Determined Contribution (NDC) aims to enhance sustainability and curtail the environmental impact in the agricultural sector by promoting fuel savings and more efficient land use through land consolidation in agricultural areas, prioritising the rehabilitation of pasture areas to ensure sustainable livestock management practices, the controlled use of fertilisers, and the implementation of modern agricultural practices that prioritise ecological balance (Özdemir M. et al., 2024).

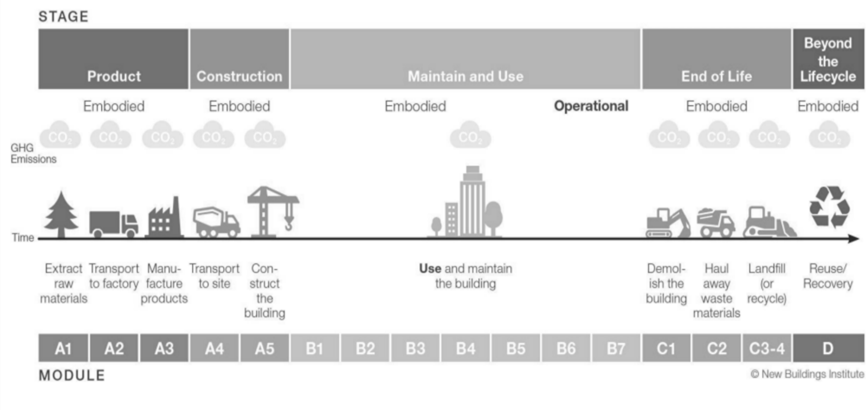
The transport sector also contributes significantly to carbon emissions. In this regard, the Ministry of Environment and Urbanisation, the Ministry of Development, and the Ministry of Transport and Infrastructure have addressed the fundamental policies and strategies for the transport sector in their plans. The plans include the establishment of a transport infrastructure that is highly accessible, fuel-efficient, comfortable, safe, environmentally friendly, cost-effective, and sustainable; the increase of the share of high-speed trains in urban rail transport, the reduction of road transport in intercity transport, the development of maritime and rail transport, the prioritisation of transport systems that use energy-efficient, clean fuel, and environmentally friendly vehicles, and the utilisation of intelligent transport systems in both intercity and urban transport.

A scholarly investigation into the obstacles and possibilities for formulating low-carbon transportation policies in Türkiye has identified the primary impediments as the absence of quantifiable objectives, social disparity (with ownership of a car and utilisation of air transport in Türkiye remaining accessible primarily to individuals of a certain social status), and an absence of inter-institutional coordination. Conversely, opportunities were identified as smart transport systems, electric vehicles and fuel technologies, fuel efficiency, and the use of low-carbon fuels such as liquefied natural gas (LNG) as an alternative to fossil fuels (Tuydes Yaman H. et al., 2024).

The Implementation of Decarbonisation Practices within the Context of Türkiye's Construction Sector

The construction and operation of buildings account for approximately one-third of global energy-related carbon emissions (Liang Y. et al., 2023). Consequently, the decarbonisation of embodied energy and operational energy use in buildings is of significant importance. Figure 3 provides a representation of the life-cycle stages of carbon emissions within the construction sector.

Figure3. Life-cycle stages of carbon emissions in construction sector



Reference: ASHRAE, 2024

In this context, there are various studies examining the embodied and operational energy use of buildings and the associated carbon emissions. For instance, a study evaluating the carbon footprint of a sample residential building in Türkiye found that the largest share of the building's carbon footprint was attributable to users' daily energy consumption. It was also observed that the life cycle carbon footprint of buildings constructed in Türkiye is 57% higher than that of buildings in EU countries. In order to reduce this, it has been recommended that users' energy consumption habits be changed, that high-efficiency HVAC systems, LED lighting, rainwater management, continuous insulation, and renewable energy sources be increased (Atmaca A. and Atmaca N., 2022). A study was conducted to estimate the energy consumption, carbon emissions, and costs per square metre over a 50-year service life for two residential buildings constructed in urban and rural areas of Gaziantep, Türkiye. The study examined the building construction, operation, and demolition phases. The findings indicate that the operational phase is predominant in both urban and rural residential buildings, with life-cycle greenhouse gas emissions amounting to 5.8

and 3.9 tonnes of CO_2 equivalent for urban and rural buildings, respectively. It has been determined that the life-cycle energy consumption and CO_2 emissions of residential buildings could be reduced by up to 22.8% and 23.4%, respectively, by using an appropriate insulation material for exterior walls (Atmaca A., 2016).

Three different parameters were identified: a historic building constructed in 1875, a new building constructed with modern structural elements similar to the plans of the historic building, and the historic building after restoration and renovation. The life cycle energy consumption and carbon emissions of these parameters were then compared with actual data obtained from the construction of a real project in Gaziantep, Türkiye. The findings suggest that the operational phase exerts a more significant influence on the building's longevity, and that the unrenovated historic structure demonstrates the highest energy consumption and carbon emissions. The subsequent presentation will address the post-restoration and modern states of the historic building. Consequently, it was determined that recently constructed buildings exhibit reduced embodied (32%) and operational (31%) energy demands in comparison to historic buildings. The renovation and restoration of historic structures using contemporary techniques resulted in a 56.6% increase in embodied energy. However, it has been suggested that although a building's life cycle energy demand and CO_2 emissions may lead to an increase in embodied energy, this can be mitigated by significantly reducing operational energy through the use of passive and active technologies, and the importance of restoring historic buildings has been emphasised (Atmaca N. et al., 2021).

In a further study, a life cycle assessment of containers in refugee camps in Türkiye was conducted to investigate the relationship between their lifespan and the energy consumed and CO_2 emissions. The assessment was conducted by selecting container dwellings with lifespans ranging from 5 to 40 years and disregarding maintenance and demolition. The findings indicate that a decade following the completion of construction, there has been a 50% reduction in total energy consumption and CO_2 emissions. This suggests a positive correlation between the service life of the structure and the reduction in CO_2 emissions. The reduction of total energy consumption, particularly embodied energy, is contingent upon the design of the systems and the selection of appropriate construction materials, with particular emphasis on the selection of suitable insulation materials (Atmaca A., 2018). In a similar vein, a further study was conducted that examined the life cycle energy analysis and life cycle CO_2 emissions analysis of two types of housing constructed in Türkiye for temporary shelter in the aftermath of a disaster. The two types of housing in question were containers and prefabricated houses. The study encompassed the building construction, operation, and demolition phases over a period of 15 and 25 years of service life. It was determined that the operational phase dominated in both container and prefabricated housing, contributing to 86-88% of primary energy requirements and 95-96% of CO_2 emissions. The life cycle energy and emission intensity of container housing was observed to be higher than that of prefabricated housing. However, the energy load is higher on a per capita basis. The embodied energy of the structures is responsible for 12-14% of the overall life cycle energy consumption. The roof and foundation of prefabricated housing accounted for the largest embedded energy and CO_2 emissions when the construction phase was considered. It has been posited that the reduction of operational energy, even if it results in a minor increase in embedded energy, should be addressed in the second phase, as the life cycle energy demand and CO_2 emissions of a house result in a minor increase in embedded energy (Atmaca N., 2017).

A study was conducted in order to compare the embedded carbon emissions of three different residential settlements at the neighbourhood level in Ankara with examples in the literature. The study found that, according to LCA analyses including building, structural, landscape, and transport infrastructure data, average emissions at the neighbourhood level amounted to 409.2 kg CO_2-eq/m^2. The data indicate that 67% of these emissions originate from buildings, 24% from transport infrastructure, and 9% from structural landscape. The development of a relationship between building and urban parameters (such as distance from the city centre and residents' income, both of which affect transport) has enabled the creation of a reference model representing collective housing projects in Türkiye (Kayaçetin N. C. and Tanyer A. M., 2020).

As illustrated by the aforementioned examples, the nZEB concept is also of significant importance in the context of decarbonisation applications, in a manner comparable to studies that focus on direct carbon emissions. The nZEB paradigm refers to a building that exhibits high energy performance, with its energy requirements being almost zero or low, and is predominantly met by energy from renewable sources, taking into account local and nearby sources. Since 2020, the requirement for new buildings in EU countries has been to achieve nZEB status. In Türkiye, the significance of this phenomenon is underscored by its incorporation into energy efficiency regulations (Maduta C. et al., 2024). At this juncture, extant studies in the literature under this heading, various assessments, and proposed solutions related to the subject have also been evaluated. The recast Energy Performance of Buildings Directive (EPBD) aims to increase energy efficiency at the settlement level with regional energy systems, focusing on the implementation of nearly zero energy levels at the regional level.

In Türkiye, urban transformation projects promote energy-efficient regional development, emphasising the need to develop energy-efficient regional heating and cooling systems and applications such as waste heat recovery (Kalaycıoğlu E. and Yılmaz Z.A., 2017). The findings of a recent study on the environmental impact of technical systems and advanced building envelopes in the context of nZEB requirements have been published. The study revealed that current nZEB requirements result in an average increase of embedded carbon by 15% across various climates, while concurrently reducing operational carbon by 30%. In the context of enhanced nZEB requirements, the potential exists for an increase in embedded carbon of 20%, a reduction in operational carbon of 30-80%, and a decrease in total lifetime carbon emissions of 32-43% (Kayaçetin N.C. and Hozatlı B., 2024).

A study examining the energy saving potential in the housing stock of Finland and Türkiye, and highlighting the importance of nZEB, found that the current insulation thicknesses in Türkiye do not meet the values required to achieve carbon neutrality and that the current legal limits for nZEB values in Türkiye are insufficient for today's conditions (Kınay U. et al., 2023). The study examined nZEB designs in terms of energy efficiency and economics in the provinces of Osmaniye, Istanbul, Konya, and Erzurum, which have different climatic conditions in Türkiye. The nZEB design process was divided into two stages. In the initial phase, the most efficient façade design was ascertained by taking into account the thermal energy requirement. In the subsequent phase, the integration of renewable energy systems, such as photovoltaic (PV) panels and wind turbines, was incorporated into the design framework. This integration was undertaken with the objective of addressing the energy requirements for various domestic applications, including heating and cooling, hot water provision, lighting, and domestic appliances. The simulation results obtained demonstrated that nZEB designs with up to 23 kWh/m², 9 kWh/m², and 3 kWh/m² of surplus energy were achieved for hot semi-arid, Mediterranean, and cold semi-arid climates, respectively. Furthermore, it was determined that if the proposed methodology is followed, the payback period for renewable energy integration, which constitutes 19% of the initial investment cost, is approximately 3.5 years (Acar U. and Kaska O., 2022).

Conclusion

The present study offers an evaluation of scientific progressions in decarbonisation, alongside the policy objectives pertinent to buildings and the construction sector. A systematic literature review and analysis have been conducted to evaluate the status of decarbonisation on a global scale, with a particular focus on different sectors in Türkiye. The research concentrated chiefly on the construction sector and nZEB buildings, thereby identifying deficiencies in Türkiye's approach to this issue. The assessments indicate that the insulation thickness of buildings in Türkiye does not meet the values required to achieve carbon neutrality. Furthermore, the legal limits for nZEB values are insufficient for today's conditions, and the life cycle carbon footprint of buildings constructed in Türkiye is higher than that of EU countries. In addition, the following factors must be considered: the existence of legal uncertainties; the inadequacy of both financial incentives and the availability of financing; the limited integration of renewable energy sources; and the absence of adequate infrastructure for performance monitoring. The primary factors hindering the implementation of nZEB applications are the substantial initial investment costs and the absence of discernible long-term economic advantages. Furthermore, there is an absence of a comprehensive system for measuring carbon emissions.

In order to address these issues, it is recommended that building users be encouraged to modify their consumption habits, that more efficient HVAC systems be integrated, that rainwater management be improved, and that the use of renewable energy sources be increased. The utilisation of construction materials characterised by a prolonged service life, with particular emphasis on insulation materials, has the potential to curtail energy consumption and CO_2 emissions. Moreover, it has been observed that urban transformation projects in Türkiye encourage the development of energy-efficient districts. The development of energy-efficient district heating and cooling systems and applications such as waste heat recovery is imperative. The improvement of legislation in this area, the augmentation of financial support, the development of local production and expertise capacities, awareness campaigns, and the implementation of monitoring systems are also of critical importance.

In conclusion, the prospect of nZEB buildings and decarbonisation targets in Türkiye represents a significant opportunity that not only increases energy efficiency but also supports environmental sustainability and economic development. In order to achieve these targets, it is essential that the public sector, private sector, and academia collaborate to develop a comprehensive roadmap. In particular, the adoption of innovative technologies, the increase in local production capacity, and the promotion of international cooperation will play a decisive role in this process. Furthermore, the development of solutions suitable for Türkiye's different climate zones and the strengthening of carbon emission monitoring infrastructure are priority steps. These efforts will not only facilitate the achievement of energy and climate goals, but also enable the creation of a more liveable, healthy, and economically stronger society.

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CHAPTER 12

READING ARCHITECTURAL MOVEMENTS THROUGH FAÇADE DESIGNS: A DEEP LEARNING–BASED APPROACH

1. MUSTAFA ALPER DÖNMEZ [1]

Introduction

Today, artificial intelligence technologies are being used increasingly widely not only in the fields of engineering and medical sciences, but also in art, design, and architecture. In particular, the capacity to work with large-scale datasets, to recognize visual patterns, and to quantify formal differences that are intuitively perceived by the human eye renders artificial intelligence a powerful tool for architectural analysis. Within the field of architecture, artificial intelligence applications are employed across a broad range of areas, including design generation, form analysis, typological classification, and the prediction of user behavior. Machine learning, one of the major subfields of artificial intelligence, produces particularly effective results in visual analysis problems due to its capacity to learn relationships within data without the need for predefined rules. Within machine learning, deep learning and object

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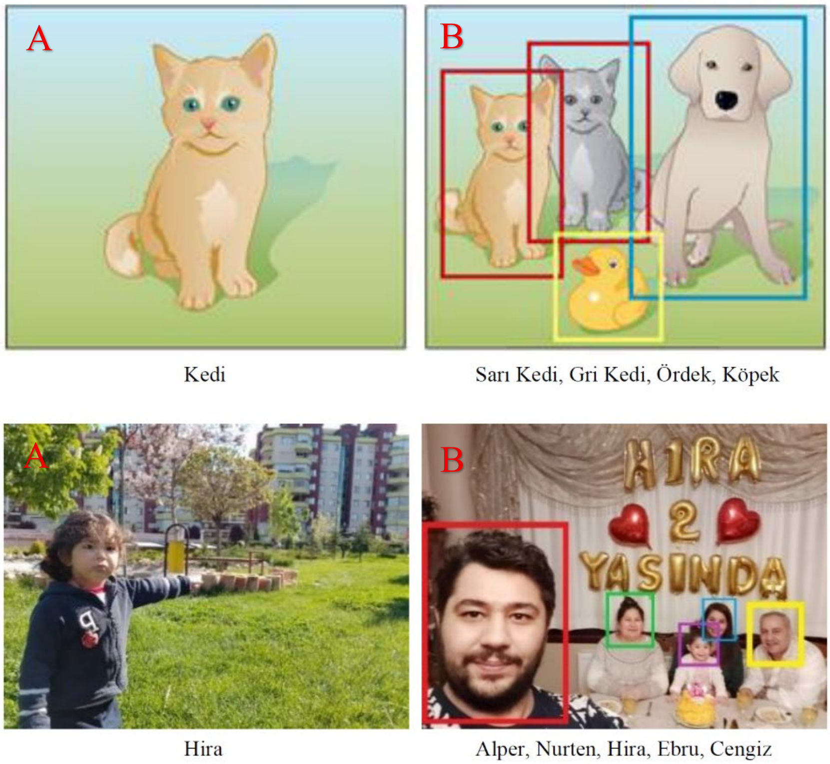
detection applications are capable of identifying specific objects, forms, or structural components within an image and subsequently classifying these elements (Figure 1).

Figure 1. ***A-*** *Object Detection* ***B-*** *Object Detection and Classification (Kalbande, 2020; Dönmez, 2021)*



In this study, the applicability of deep learning–based object detection approaches for the visual identification and differentiation of architectural movements is examined. Architectural movements can be interpreted not only through historical or theoretical texts but also through visual characteristics such as façade organization, mass composition, geometric order, material language, and formal repetitions. In this context, object detection methods possess the potential to perform classification by learning the characteristic components of architectural movements.

Within the scope of this study, four architectural movements—First National Architecture, Brutalism, Futurism, and Deconstructivism—were examined, and a deep learning–based object detection model was developed using visual data belonging to these movements. The model was initially trained on images representing the four architectural movements and subsequently tested on new sample images. As a result, the regional- and pixel-level analytical capacity of Mask R-CNN in the analysis of architectural façades was discussed. Furthermore, it was demonstrated that hybrid and transitional architectural movement examples possess the potential to generate algorithmic ambiguity.

Material and Method

1. Architectural Movements/Style

Within the scope of the study, a visual dataset was constructed based on façade photographs of buildings representing four different architectural movements. These architectural movements are as follows:

- **First (Turkish) National Architectural Movement**

The First National Architectural Movement, founded on an ideology dominated by nationalism and Turkism, primarily emerged with the proclamation of the II. Meşrutiyet in 1908 and continued to develop until the 1930s. This movement aimed to make the pursuit of national identity visible through architecture (Yaldız & Parlak, 2018; Kopuz, 2016).

This movement emerged as a reaction against Western-origin eclectic and neoclassical styles, aiming to reinterpret the formal, decorative, and structural elements of Ottoman and Seljuk architecture using contemporary construction techniques (Yaldız &

Parlak, 2018; Kopuz, 2016). Turkish architects educated in the West sought to create a national synthesis in architecture, believing that this could only be achieved through the revival of historical architectural elements (Özcan, 2002). The influence of this movement remained largely confined to public buildings (Yazar & Kishalı, 2019).

The characteristic features of the movement include symmetrical façades and floor plans, monumental scale, prominent entrance axes, arches, wide eaves, domes, as well as tile and stone ornamentation (Aktemur & Arslan, 2010; Özcan, 2002). The façades particularly emphasize traditional motifs and are designed to serve as instruments of public representation. Extensive use is made of carved and stonework elements derived from Seljuk and Ottoman architecture (Aktemur & Arslan, 2010). Compared to other contemporary buildings, these façades exhibit a richer decorative quality. The influence of the First National Architectural Movement is especially manifested in the dynamism and detailed work on façades. Consequently, in this movement, the plan and spatial organization remain secondary (Ertuğrul, 2007).

In this context, the First National Architectural Movement offers significant data potential for AI-based object detection and classification applications, due to its formally definable characteristics and recurring visual codes.

- **Brutalism**

Brutalism emerged as one of the prominent movements of modern architecture in Europe and America, particularly between 1950 and 1980, following World War II (Kahraman, 2024). Deriving its name from the French term béton brut (raw concrete), this approach centers on concepts of honesty, functionality, and structural clarity in architecture. Ornamentation is deliberately rejected in Brutalist architecture; instead, structure, material, and construction techniques become the direct expression of the building itself. As Reyner Banham described, Brutalism embodies an ethical stance that reveals rather than conceals how a building is constructed (Banham, 1966). In this context, exposed concrete surfaces (béton brut), heavy and massive volumes, and sharp geometries are among the distinguishing features of the movement (Curtis, 1996; Frampton, 2007). Façade elements such as window openings often exhibit irregular proportions, and interior functions are often legible from the exterior, reflecting the Brutalist design ethos that prioritizes material and programmatic honesty (Colquhoun, 2002).

This pronounced emphasis on massing and materiality makes Brutalism a highly distinguishable architectural movement for visual analysis and object detection. The texture of concrete surfaces, the raw use of materials, the block-like forms, and the legibility of structural elements provide visual patterns that can be readily learned by deep learning models.

- **Futurism**

Futurism, an avant-garde movement that emerged in Italy in the early 20th century, influenced not only architecture but also art, literature, and design. The movement sought to reject historical and traditional values, celebrating speed, motion, technology, mechanization, and dynamic lifestyles. In this study, the concept of Futurism is addressed not as the historical avant-garde movement itself, but rather in the context of its reinterpretation in contemporary architecture, namely neo-futurist tendencies.

In architecture, Futurism is characterized by fluid and curvilinear forms, sharp diagonals, overlapping volumes, pronounced perspectival effects, and dynamic mass compositions. Buildings are designed to be perceived not as static objects but as organisms in motion. The use of glass, steel, and other modern materials constitutes an important element supporting the concept of technological progress (Frampton, 2007).

The dynamic formal language of this movement and its structural compositions that deviate from conventional geometries provide a significant testbed for visual recognition systems. In particular, façades that convey a sense of motion, curved surfaces, and unconventional volumetric relationships are well-suited for evaluating the capacity of object detection algorithms to discriminate formal differences.

- **Deconstructivism**

Deconstructivism is an architectural approach that began to exert influence in architectural theory from the 1980s onward and is associated with postmodern thought. This movement deliberately disrupts classical architectural concepts such as order, symmetry, and unity, aiming to generate a new spatial narrative through uncertainty, disorder, and controlled chaos (Vidler, 2000).

In Deconstructivist architecture, the façade is not treated as a symmetrical or unified surface; rather, it is designed according to a fragmented and discontinuous compositional logic. Diagonal lines replace traditional horizontal and vertical order, and broken, misaligned surfaces create the perception of movement, making the façade appear dynamic rather than static (Wigley, 1993). In this approach, the façade does not directly reveal the building's structural system; the structure is often concealed or unreadable from the exterior (Eisenman, 1999). Consequently, the façade does not explicitly disclose the building's function or interior layout. Windows and openings are positioned without adherence to regular axes or rhythmic sequences, producing a sense of randomness (Vidler, 2000). Materials such as glass, metal, and concrete are combined in a deliberately discordant manner, and the juxtaposition of varied textures, colors, and reflectivity intentionally complicates the relationship between solid and void (Tschumi, 1996).

Deconstructivist buildings, which exhibit high visual complexity, present challenging yet instructive examples for AI-based analysis and classification. The fragmented forms and irregular geometries provide a valuable opportunity to test a model's capacity to learn abstract and complex formal patterns.

2. Data Set and Visualization Preparation

For the training of the Mask R-CNN–based algorithm developed in this study, a total of 316 images representing four different architectural movements were compiled. Of these, 58 images were obtained through fieldwork, while the remaining 258 were sourced from publicly available resources. During the fieldwork, a digital camera with a 64 MP resolution and a 5.43 mm F/1.89 aperture was used to capture images in RGB format at a resolution of 4624×3472 pixels and 72 dpi. The publicly sourced images were used solely for academic analysis purposes.

Of the 316 compiled images, 140 depicted the First National Architectural Movement, 42 represented Deconstructivism, 48 represented Brutalism, and 70 depicted Futurism. These images were annotated according to their architectural periods using the LabelMe program. The remaining 16 images were set aside unannotated for testing the algorithm. Class imbalance within the dataset was considered an important factor when interpreting the results. In the next step, the annotated images were converted to JSON format using LabelMe, with 70% allocated to the training folder and 30% to the validation folder. The resulting training and validation datasets were then converted to COCO format, making them ready for use with the algorithm.

3. Method: Mask R-CNN

In this study, the Mask R-CNN (Mask Region-Based Convolutional Neural Network) algorithm was selected to distinguish the visual characteristics of architectural movements and to analyze the formal components of buildings in detail. Mask R-CNN is an advanced deep learning model capable of both object detection and instance-based segmentation. Its ability to identify not only the locations of objects within an image but also their pixel-level boundaries makes this method particularly suitable for the analysis of architectural visuals.

Within the scope of this study, Mask R-CNN was chosen because of its potential to learn not only the overall massing of architectural movements but also detailed visual features such as façade elements, structural emphases, and form fragmentation. Classification models that consider images only holistically (e.g., CNN-based image classification) often prove insufficient for capturing subtle differences between architectural styles. In contrast, Mask R-CNN offers a significant advantage by enabling the learning of local and regional visual patterns separately.

Thanks to its core component, the Region Proposal Network (RPN), Mask R-CNN can automatically detect potential object regions within an image. **The Region Proposal Network** capability of Mask R-CNN enables, in the context of architectural structures, this capability enables the identification of:

- Façade surfaces
- Window and opening arrangements
- Mass projections
- Structural elements
- Fragmented or fluid forms e.g,

This functionality allows for the separate analysis of critical regions that distinguish architectural movements. Such regional differentiation particularly enhances classification performance between approaches with prominent façade elements, like Brutalism and the First National Architectural Movement, and movements with fragmented and irregular geometries, such as Deconstructivism.

Another key advantage of Mask R-CNN is its **pixel-level masking capability**. This feature is particularly critical in the context of architectural analysis, as architectural style is often interpreted not from the building as a whole, but through:

- Mass continuities
- Façade disruptions
- Surface textures
- Geometric distortions

In movements such as Deconstructivism and Futurism, where building forms lack clear boundaries and volumes overlap, traditional bounding-box–based models face significant challenges. Mask R-CNN overcomes this limitation by segmenting these complex geometries at the pixel level, enabling a comprehensive analysis of architectural forms.

Thanks to its **multi-scale feature extraction capability** through the Feature Pyramid Network (FPN) architecture, Mask R-CNN can simultaneously learn both large-scale massing and fine architectural details. This ability to handle **complex visual patterns** enables the model to more accurately represent both macro- and micro-scale differences between architectural styles.

In conclusion, the primary reason for choosing Mask R-CNN in this study is its ability to distinguish architectural styles not merely based on visual similarities, but through a holistic analysis of formal, spatial, and geometric components. The model's capabilities in **regional learning**, **pixel-level masking**, and **multi-scale feature extraction** provide high accuracy and interpretability for the architectural style recognition problem.

The algorithm's core architecture employs Mask R-CNN, with **ResNet-101** selected as its backbone. ResNet-101 is a convolutional neural network comprising 101 layers. Despite its increased depth, ResNet-101 does not suffer from the degradation problem commonly encountered in very deep networks (He et al., 2016).

In the final stage, the algorithm was trained using the **TensorFlow** framework. TensorFlow is a free and open-source software library developed by Google Brain in 2015 for conducting machine learning and deep neural network research. Its compatibility with multiple programming languages allows developers to use it conveniently. For this reason, TensorFlow has become one of the most widely used and preferred frameworks in deep learning studies.

For the algorithm, a maximum of **20,000 iteration steps** was tested, and the training was completed in **2 hours and 33 minutes**. The **Total Loss** graph, which indicates the deviation of the algorithm's predicted values from the actual values, is presented in Figure 2. A Total Loss value close to zero demonstrates the high reliability of the algorithm's predictions (Rahman et al., 2019). Similarly, the **Accuracy** graph (Figure 3) shows that the accuracy rate increases as the number of iterations rises.

Figure 2. *Total Loss Graph of the Mask R-CNN Model*

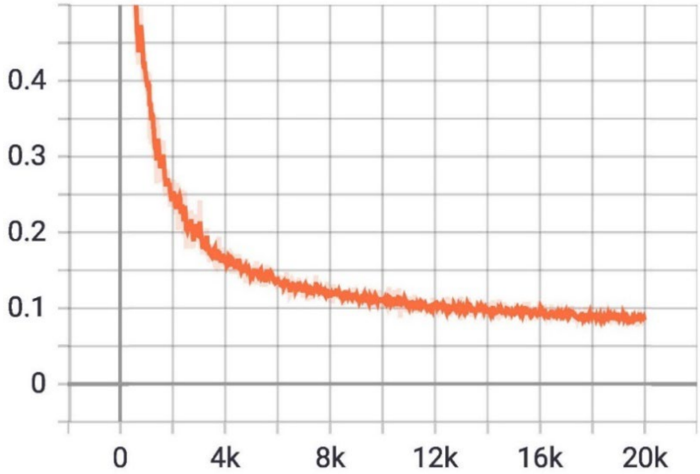
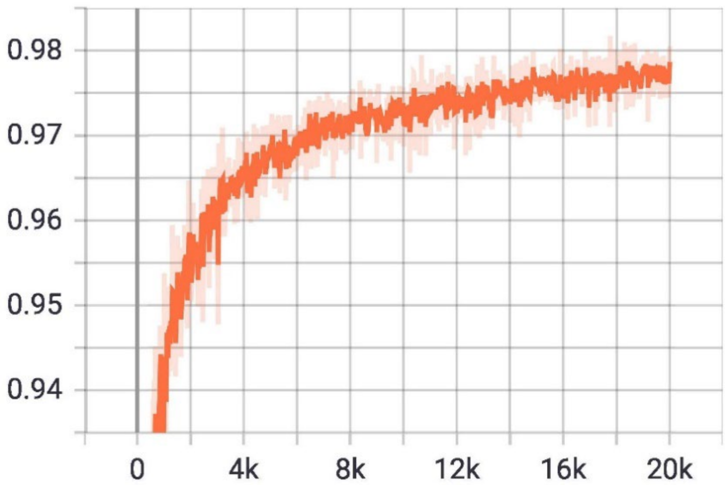


Figure 3. *Mask R-CNN Accuracy*



4. Test Phase

After the training was completed, four sample images representing each architectural style were analyzed by the system, and the model's classification performance as well as the visual elements it focused on were evaluated. One sample image per architectural style is presented in this study.

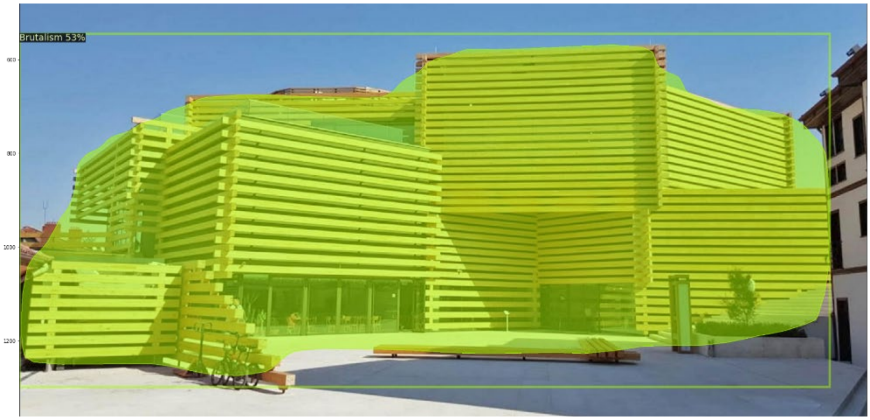
Results and Discussion

Following the completion of the algorithm's training, the developed approach was tested to evaluate its validity by presenting four previously unseen images representing each architectural style to the model (Figures 4–11). The findings obtained at this stage were analyzed comparatively, and the system's success in identifying architectural styles was discussed.

Figure 4. *Odunpazarı Modern Museum (OMM)*

Source: www.themagger.com

Figure 5. OMM Mask R-CNN Result - Brutalism %53



When the image of the Odunpazarı Modern Museum was analyzed by the algorithm (as indicated in the top-left corner of the image), the building was classified as 53% Brutalist architecture (Figure 5). The extensive use of natural wood on the façade is rarely observed in architectural approaches such as the First National Architecture, Deconstructivism, or Futurism. In contrast, presenting the material in its raw, unadorned form aligns with one of the core principles of Brutalism. In this context, the direct use of wood with its raw and massive character on the façade of the Odunpazarı Modern Museum can be interpreted as a contemporary expression of the Brutalist principle of "honest material expression."

In Deconstructivism and Futurism, diagonal lines often replace the traditional horizontal and vertical axes in façade composition. However, the Odunpazarı Modern Museum exhibits a more legible, orthogonal façade organization. While symmetry is a fundamental design principle in the First National Architecture, this building adopts an asymmetrical sense of balance. Based on these formal and material characteristics, the algorithm's classification of the building as Brutalist can be considered a broadly accurate result.

However, when examining the reasons behind the relatively low classification confidence of 53%, it is observed that, although the building embodies the Brutalist principles of structural honesty, massiveness, and unadorned expression, the principle of “material expressed as is” is typically associated with raw concrete in the Brutalism literature. In the case of the Odunpazarı Modern Museum, this principle is reinterpreted through the use of massive timber (Figure 4).

This situation leads to the interpretation of the building not as a pure stylistic representation, but as a local, contemporary, and hybrid interpretation of Brutalist thought. Additionally, the building’s asymmetrical mass balance and the stacking of volumetric forms contain formal references that overlap with Deconstructivist architecture. Consequently, the structure occupies an intermediate zone where the boundaries between architectural styles are blurred. Thus, rather than fully representing the rigid formal codes of a single architectural movement, the building exhibits a hybrid architectural language formed by the layering of different approaches. This stylistic hybridity creates uncertainty in the algorithm’s decision-making process, resulting in a limited classification confidence.

Figure 6. *İrfan Medeniyeti Research and Culture Center (İMRCC)*

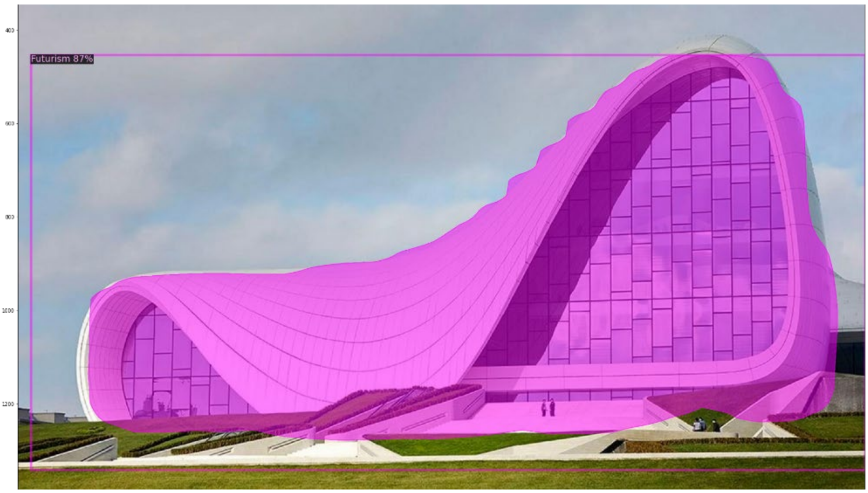
__Figure 7.__ İMRCC Mask R-CNN Result – First National Architecture %100

When the visual representation of the İrfan Medeniyeti Research and Culture Center was analyzed by the algorithm, it classified the building as belonging to the First National Architectural Movement with 100% confidence (Figure 7). This outcome can be attributed to the building's pronounced façade features that are uniquely characteristic of the First National Architectural Movement. The presence of tile ornamentation on the façade, religious elements such as a dome above the entrance axis, the use of string courses to emphasize floor divisions, and variations in window typologies between floors all stand out as distinctive features not commonly found in other architectural movements (Figure 6). In addition, the symmetrical arrangement of the façade further distinguishes this building from Futurist and Deconstructivist architectural approaches. Although the façade contains occasional arched window openings and curvilinear decorative elements, it is evident that the algorithm did not associate these features with Futurism or Deconstructivism, instead basing its classification on the more dominant and characteristic façade elements.

Figure 8. *Heydar Aliyev Cultural Center (HACC)*

Source: www.arkitektuel.com

Figure 9. *HACC Mask R-CNN Result – Futurism %87*



The algorithm classified the Heydar Aliyev Cultural Center as belonging to the Futurism movement with 87% confidence (Figure 9). The asymmetric massing observed in the façade design causes the building to diverge significantly from both the horizontal and vertical organizational principles dominant in the First National

Architectural Movement and the heavy, massive, and angular geometries characteristic of Brutalist architecture. The façade's asymmetrical composition and unornamented, minimalist expression stand in clear contrast to the First National Architectural Movement's fundamental design principles of symmetry and ornamentation (Figure 8).

Although the building's character might be expected to relate to the plain and unadorned façades commonly seen in Brutalism, the use of glass and metal instead of raw concrete limits its association with the Brutalist movement. On the other hand, the algorithm's decision not to directly associate the building's fluid and curvilinear forms with Deconstructivism can be considered a theoretically debatable point, highlighting the complex interplay of formal characteristics in the building's classification.

Within this context, the building's classification as 87% Futurist suggests that it does not represent a pure instance of a single architectural movement, but rather exhibits a hybrid character incorporating elements of Brutalist and Deconstructivist approaches. The algorithm's 87% classification indicates that the building predominantly displays Futurist features, while certain formal and material-based elements introduce a minor degree of ambiguity between architectural styles.

Figure 10. *Konya Meram Municipality Building (KMMB)*

Source: www.merhabahaber.com

Unlike the other examples, the algorithm analyzed the entirety of the Konya Meram Municipality Building as 99% Deconstructivist, while additionally classifying the right section of the building as 53% Brutalist (Figure 11). Although raw concrete is not used on the building’s façade, the monolithic mass perception and limited formal variation observed in this section are thought to have caused the algorithm to form a weak match with Brutalism. This suggests that the algorithm predominantly makes its classification decisions based on formal visual patterns.

__Figure 11.__ KMMB Mask R-CNN Result – Deconstructivsm %99, Brutalism %53

The classification of the building's left mass, as well as the structure as a whole, as Deconstructivist stems from the algorithm's dominant perception of formal disruption and geometric discontinuity. Directional breaks observed in the left mass, the intensive use of negative spaces, and ambiguities in the façade–structure relationship reinforce visual patterns associated with Deconstructivist architecture.

In conclusion, this study aimed not to provide a holistic definition of architectural styles, but to test the algorithmic distinguishability of visual patterns readable from façades. The findings demonstrate that the Mask R-CNN model is capable of discerning formal patterns specific to architectural movements. Massing density and surface continuity were successfully detected in Brutalist buildings; diagonal and fluid forms in Futurist structures; and fragmented geometries and irregular massing relationships in Deconstructivist examples. Buildings of the First National Architectural Movement stood out for their symmetrical façade arrangements and ornamental emphasis.

Conclusion

Artificial intelligence can be regarded not as an actor that rewrites architectural history, but as an analytical tool that conveys architectural knowledge to a different interpretive plane. Such approaches offer new opportunities for architectural education, digital archiving, and theoretical analysis. Future studies are recommended to explore larger datasets, hybrid models, and multi-layered analyses that also incorporate cultural context.

This study demonstrates that deep learning–based object detection models can serve as an effective analytical tool for analyzing and classifying architectural styles based on façade characteristics. The analyses conducted using the Mask R-CNN architecture show that architectural styles can be evaluated not only through historical and theoretical texts but also via visually quantifiable features such as geometric organization, mass composition, material usage, and formal continuities.

The findings indicate that the model successfully learns style-specific formal patterns at both macro-scale (overall mass composition and façade organization) and micro-scale levels (surface continuity, arrangement of openings, and form disruptions). In the First National Architectural Movement, symmetry and ornamentation were identified; in Brutalist architecture, mass density and surface continuity; in Futurist buildings, fluid and dynamic geometries; and in Deconstructivist examples, fragmented forms and geometric discontinuities—each detected by the algorithm as distinguishable visual codes.

Moreover, the relatively lower confidence levels observed in the classification of hybrid or transitional architectural forms indicate that architectural movements are not always represented as pure, discrete stylistic categories. This finding demonstrates that AI-based classification systems evaluate architectural styles primarily through visual and geometric behaviors rather than theoretical or historical intentions. Consequently, instances in which the algorithm exhibits uncertainty should not be seen merely as a limitation; rather, they can be considered an important insight that reveals the inherent stylistic continuities and overlaps present in architectural history.

From a methodological perspective, the regional learning and pixel-level masking capabilities of Mask R-CNN enable the analysis of architectural façades not only in terms of their overall form but also through their local and fragmented features. This capability enhances the interpretability of model outputs and allows for a spatially grounded understanding in studies of architectural style recognition.

In conclusion, artificial intelligence should not be regarded as a tool that redefines or replaces architectural history, but rather as a complementary and analytical approach that offers a new interpretive layer for architectural knowledge. Such deep learning–based methods provide novel research opportunities in architectural education, digital archiving, and theoretical analysis. Future studies would benefit from employing larger and more balanced datasets, integrating semantic data into visual analyses, and thereby enabling a more comprehensive interpretation of architectural styles through Artificial intelligence.

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