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Article

Reconstruction of public space in the context of the continuity of the urban spine: Mersin Cumhuriyet Square and Atatürk Boulevard Çamlıbel urban design contest

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ABSTRACT

Mersin has been a prominent settlement in the Cilicia Region since antiquity, with its urbanization shaped by its port, trade and maritime identities, originating from a fishing harbor. The city's development was primarily driven by trade and port activities, initially concentrated around Uray Street, the commercial hub, before expanding towards Atatürk Street, forming the urban spine. Over time, this historical fabric gave rise to distinctive urban spaces, with Uray Street emerging as a central element of urban identity. However, uncoordinated planning decisions and implementations have led to the erosion of original urban spaces, weakening the historical continuity between the city center and the Uray-Atatürk Street axis. The construction of a new port has diminished the significance of key focal points such as Customs Square, while the proliferation of shopping malls has undermined the area's commercial fabric. Moreover, the deterioration of previously integrated transportation networks has fragmented vital public spaces, including Customs Square, Yoghurt Bazaar and Lovers' Park, disrupting spatial continuity. Incompatible land use and inadequate planning have created undefined, disconnected spaces, obstructing pedestrian movement. Physical and spatial barriers such as driveways, parked vehicles, elevation differences, and insufficient shading exacerbate disconnection, while impermeable surfaces such as concrete and asphalt intensify the heat island effect, diminishing the area's functionality and livability. In response to these problems, urban transformation efforts accelerated with the Cumhuriyet Square and Atatürk Street Çamlıbel Urban Design Contest organized by Mersin Municipality in 2021. While the winning project, currently being implemented, prioritizes the restoration, sustainability and reinforcement of the urban spine, this study situates the scope and boundaries of the competition project, which primarily focuses on the Atatürk Street section, within the broader contextual framework of the Uray-Atatürk axis. By doing so, it provides a comprehensive analysis of the formation, spatial and functional characteristics of this axis, while also offering a holistic evaluation of the changes, interruptions and ruptures that have occurred over time. The methodology includes literature and archive research to identify extensive potential as well as defects and deficiencies. It also involves an analysis of urban mobility, public space reorganization, pedestrianization and transportation regulations, followed by an evaluation aimed at proposing a comprehensive solution package consisting of planning strategies and decision-making approaches related to spatial design. Offering strategies for the preservation and transformation of the urban spine, this study not only provides design insights, but also serves as a model for other cities in urban planning and design.

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Rather than being confined to a theoretical literature review on the spine concept, it integrates theory with practice, analyzing how each spatial element constituting the spine is supported by physical, functional and social planning strategies. Through this approach, the study offers a perspective by elucidating the tangible manifestations of the spine concept within an applied framework. Additionally, it provides insight into the urban spine's fundamental role in ensuring urban order, aesthetics and identity through both theoretical and practical approaches. Findings from the analysis of pedestrian movement dynamics revealed a gradual decline in foot traffic along the historically significant Atatürk-Uray Axis, disrupting this corridor's continuity. Deficiencies in pedestrian connectivity were identified not only along the primary east-west axis but also on secondary north-south routes. To address these gaps, a comprehensive pedestrianization strategy, incorporating dedicated bicycle lanes, has been implemented along Atatürk-Uray Street. Additionally, infrastructure enhancements, including overpasses, bridges and pedestrian crossings, have been proposed to strengthen connectivity between Historic Uray Street, the newly developed People's Garden and Atatürk Park. Extending from Uray Street, Atatürk Street serves as a crucial link within the contemporary urban structure, encompassing key historical landmarks central to the city's core. Its integration, reinforced through enhanced horizontal and vertical connections, fosters a cohesive interplay of commercial, cultural and recreational functions, ensuring both spatial continuity and the preservation of historical identity. The area's strong commercial character, inherited from Uray Street, has been harmonized with local dynamics by fostering interactions with prominent public spaces, particularly Cumhuriyet Square and Lovers' Park. This strategy has resulted in high-quality, multifunctional urban spaces that enhance community engagement and urban vibrancy. In summary, the urban spine is crucial in shaping urban identity and ensuring city continuity. Its functions of providing structural support, connectivity, balance, reinforcement, and hierarchical organization should be comprehensively analyzed from a design perspective to address both micro and macro-scale urban contexts. The spine is not merely a facilitator of movement but also a system integrating physical, socio-cultural, and economic networks. This study demonstrates that strengthening the urban spine is not merely a theoretical framework but also a feasible and implementable strategy.

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INTRODUCTION

The spine, a structural element in some living organisms, is defined as a structure that keeps the body upright. In other words, the spine connects all parts of the body from the head to the coccyx and serves as the main support (Güncel Türkçe Sözlük, 2025). Based on this definition, Ekinci and Aktan (2017) adapted the structural characteristics of the spine to spatial contexts and examined them within the framework of the principles of bearing, binding, hierarchy, support and axis formation. They stated that when the spine is positioned at the center of gravity, it assumes a load-bearing function within spatial structures and acts as a connector by linking at least two elements, structures, or functions. Additionally, they demonstrated that the spine establishes a hierarchy by organizing various urban functions in a specific order, creating a composition and grading them within a spatiotemporal context according to spatial needs. They further stated that urban spines, which constitute the densest areas of cities, serve to protect and sustain socio-economic values through economic, social, cultural and religious elements. Moreover, they emphasized that the urban macroform is shaped by the development of a linear, curvilinear, or topography-dependent axis.

Spine-shaped circulation systems have played a significant role throughout history in the shaping and planning of cities. This strong and aesthetically impactful urban design element can be observed in ancient Greek, Roman, medieval, Renaissance and Baroque cities; in 18th- and 19th-century European and American cities; in Brasília, the capital of Brazil; and in the planning of 20th-century capitals. Furthermore, the spine-shaped structure is a key component of urban planning principles such as the Linear City and the City Beautiful Movement, both of which aim to define the ideal form of cities (Krier & Rowe, 1979). According to Krier (1979), a spine-shaped planning approach has consistently served as an indicator of a civilization's level of development.

Urban spines have been used for various purposes in different urban plans and have played various roles. Bacon (1967) defined the urban spine as a system of movement shaped by spatial elements with a strong influence and stated that it functions as a link between different urban areas. Furthermore, according to Bacon (1967), urban spines should also be considered a tool for political influence. Mortazavi (1997) stated that, in addition to their socio-economic functions, urban spines serve as a symbolic representation of the modern city, a commercial center, an open space, or a demonstration area.

Krier (1979) defines the concept of a "spine" as a central linear formation that structures the city's layout. Spines are regarded as a strong element that integrates functionality, aesthetics and social order within the urban fabric. According to Krier (1979), the spine is not merely a transportation route but a fundamental component that upholds urban order and social structure. As an element that unifies the city both physically and socially by integrating different areas with one another, the spine plays a central role in shaping the overall structure and identity of the city. Krier (1979) perceives the spine not just as a transport corridor but as a medium for influencing the city's aesthetic and social dynamics. Functioning as urban arterial routes, spines enhance connectivity and mobility by serving as linear connectors that link different areas. Krier (1979) also argues that urban arterial roads should be distinguished by unique architectural features. By doing so, he asserts that the urban circulation system will become more defined and aesthetically cohesive, ultimately imparting meaning, character and identity to the city.

Büyükcivelek (2012) defines the urban spine not only as a system that facilitates pedestrian and vehicular circulation but also as a collector and distributor that brings together various urban activities such as trade, public spaces, tourism centers, business districts and educational institutions. Additionally, it connects major city entrances, including railway stations, airports and bus terminals. In this context, urban spines are described as forming an organized, legible and functional urban system. Lynch (1960) established a relationship between the spine and the city's image by stating that urban elements are positioned along urban spines. Büyükcivelek (2012) emphasized that urban spines play a central role in shaping daily life. The concentration of social and economic activities on urban spines through a structured hierarchy, the integration of different urban systems within them and the outward expansion of these systems into the city underline the importance of spines in the process of urban image formation.

To summarize, the urban spine primarily functions as a movement system while simultaneously serving as a connector between spaces. Encompassing both pedestrian and vehicular circulation, it integrates social, cultural and economic aspects, forming a cohesive structure within the existing transportation network. Furthermore, its inclusion of elements such as squares, roads and signage contributes to urban order, enhances aesthetics and reinforces urban identity.

The research is grounded in the award-winning first-prize project developed by ECO.laud (ECO.laud, 2021) for the Cumhuriyet Square and Atatürk Boulevard Çamlıbel Urban Design Contest (Mersin Büyükşehir Belediyesi, 2021), organized by the Mersin Municipality. The competition brief emphasized the redesign of public spaces along Atatürk Street, a key urban corridor stretching from the northeast to the southwest of Mersin. This area includes Cumhuriyet Square and the historically vibrant Çamlıbel district, once a dynamic urban hub that had lost vitality due to the city's westward and northward expansion. The brief emphasized the preservation of historical connections between these spaces, the maintenance of their distinct identities and the cultivation of a coexistence culture that reflects Mersin's multicultural character, especially along Atatürk Street, which serves as Çamlıbel's primary axis.

Both the competition brief and jury evaluations identified the site as a crucial component of Mersin's urban spine, emphasizing its rich spatial qualities and untapped potential to physically and functionally reconnect the city. Urban analyses supported these observations, revealing the area as a pivotal transition zone between the historic core and newer developments. Characterized by heavily used public spaces, including commercially active squares and streets, the findings confirmed the competition site as a critical segment of the urban spine, bridging historical and contemporary urban layers. Consequently, the primary design objective was to reinforce Mersin's fragmented urban spine through five key principles: bearing, binding, hierarchy, support and axis formation. These principles guided the sub-objectives, aligning with the competition's focus on sustainability, identity preservation, mobility integration and cultural revitalization.

In line with this objective, the study initially focuses on Uray Street and Atatürk Street, which collectively form the city's primary urban spine. These streets were analyzed with respect to movement, connectivity and functionality. To decode the spine's structural logic, the study investigates its historical evolution, the planning interventions that influenced it, its spatial characteristics and its role within the broader urban system. Subsequently, transformations, disruptions and fractures along the spine were identified, leading to context-sensitive proposals for areas requiring restoration or reinforcement.

Developed within the scope of the competition, the study addresses spatial and functional fragmentation in Mersin's historic center while incorporating key requirements from the brief, including social inclusivity, cultural revitalization, accessibility and sustainability. The jury commended the study's spatial clarity, coherent integration of urban layers and contextual sensitivity, qualities that embody the theoretical underpinnings of the spine-based approach. The core design objective was to strengthen the compromised urban spine through five fundamental spatial principles: bearing, binding, hierarchy, support and axis formation. These principles structured the design's sub-objectives, aligning with both the competition criteria and urban analysis findings.

This study examines the urban spine as both a guiding design philosophy and a conceptual framework for addressing spatial challenges in urban environments. It positions Mersin's urban spine through a comparative analysis of established theoretical frameworks, including Bacon (1967), Krier (1979), Lynch (1960) and Ekinci and Aktan (2017). The analysis characterizes the spine not as a mere thoroughfare but as a multifunctional element central to the city's structure, functioning as a load-bearing axis, a socio-economic connector and a key factor in urban image formation. Methodologically, the study stands out for its use of location-based digital tools, particularly GPS mobility data from the Strava application (Strava, 2021), which, through correlation with on-site observations, supported spatial analysis and facilitated evidence-based design decisions. Thus, the study contributes both theoretically and methodologically to contemporary urban design, proposing a context-driven yet scalable model that demonstrates how theoretical frameworks can guide practice in complex urban settings.

Events and Planning Decisions Affecting the Formation of Mersin's Urban Spine

Mersin, situated along Turkey's southern Mediterranean coastline, has served as one of the Cilician Region's most prominent settlements since antiquity. The city's urbanization process originated as a humble fishing settlement before progressively developing into a major port city, embodying dual identities as both a commercial hub and coastal urban center. This maritime character, combined with subsequent planning interventions, proved instrumental in forming Mersin's distinctive urban spine. Through comprehensive spatial analysis, this study not only identifies the city's primary urban spine but also conducts an in-depth examination of Uray Street and its continuation as Atatürk Street, both of which constitute essential components that are intrinsically linked to the competition site.

The first stage of the study examines the transformation of the city's spatial structure in relation to its port-city identity, along with the socio-economic dynamics, commercial activities and transportation networks associated with this identity. This analysis demonstrates how the urban spine initially emerged in the historic city center. The second stage investigates the evolution of this spine in connection with the city's broader development, assessing Mersin's morphological growth and urban planning processes to elucidate the spatial dynamics that influenced and modified the spine over time. Finally, the study conducts a detailed analysis of Uray Street and Atatürk Street, which are historically significant and still-active segments of Mersin's urban spine, by evaluating spatial transformations within the area, encompassing existing, lost and altered spaces, as well as their current characteristics and future potential.

Mersin Port and its related trade activities have played a significant role in the establishment and growth of the city. Similar to other 19th-century Middle Eastern port cities, Mersin became a focal point due to the expansion of the capitalist economy and historical events driven by increasing commercial activities (Selvi Ünlü, 2007). After the Tarsus and Kazanlı piers lost their function as harbors, Mersin's economic and spatial development accelerated (Adıyeke & Adıyeke, 2004; Selvi Ünlü, 2007). Ünlü (2007) provides a broader perspective on the reasons for Mersin's development and lists the following factors: the increase in cotton production in Çukurova due to the American Civil War, migration to Mersin from Eastern Mediterranean cities and neighboring regions and the use of timber from the Taurus Mountains for the construction of the Suez Canal and the railway. During this period, significant changes took place in the city; maritime trade agencies were established and the consulates of several countries relocated from Tarsus to Mersin (Durak, 2006). As a result of these developments, Mersin developed a cosmopolitan socio-economic structure, particularly attracting non-Muslim communities to the city center. This port-driven transformation was further accelerated by the expansion of Mersin's transport infrastructure. In addition to maritime trade, infrastructure developments such as the Mersin-Adana paved road (built in 1873), the Mersin-Adana railway (completed in 1886) and the Mersin-Silifke-Mut-Karaman road (constructed in the early 20th century) contributed to Mersin's emergence as a key regional center (Akkaya, 2004).

The transformation and development of Mersin's urban can be traced through the city's planning processes. Mersin's first urban plan was developed by Herman Jansen in 1938. The Jansen Plan aimed to highlight two key aspects of the city: the harbor, which was designed to boost commercial activities and the sea, reinforcing Mersin's identity as a "Coastal City" (Ünlü, 2009). The area between İstiklal Caddesi and Efrenk (Müftü) Stream was developed in accordance with the core principles of the Jansen Plan. However, this plan proved inadequate in accommodating the rapidly growing urban population and the expanding city structure.

Mersin's first comprehensive urban plan was developed by İller Bank, envisioning a westward expansion along İstiklal, Silifke and Atatürk Streets. This plan defined the macro-form of the city as a compact urban model, where residential density gradually decreased from the center to the periphery (Selvi Ünlü & Ünlü, 2008). The İller Bank plan was revised in 1976, yet the modifications failed to adequately regulate urban development. In 1980, a 1/25,000-scale urban environmental development plan was formulated in collaboration with the Ministry of Environment and Urbanization and Mersin Municipality (Hisarlı, 1988). Nonetheless, even this plan fell short in addressing Mersin's rapid urbanization dynamics. Finally, the 1/25,000-scale Master Plan, developed by Mersin Metropolitan Municipality in 2008, aimed to alleviate pressure on the city center and establish a development corridor extending eastward toward the port (Figure 1).

From the city's foundation to the present, Uray Street and Atatürk Street, which have constituted the city's urban spine, have maintained their dynamic structure in the city center. This dynamism has extended to perpendicular streets such as Hastane Street and Çakmak Street, as well as parallel streets like Silifke and İstiklal Streets. This expansion also occurred functionally, as the commercial identity of Uray Street gradually spread to adjacent streets.

A tram line built in 1910 played a crucial role in shaping Uray and Atatürk Streets as the spine of the historic city

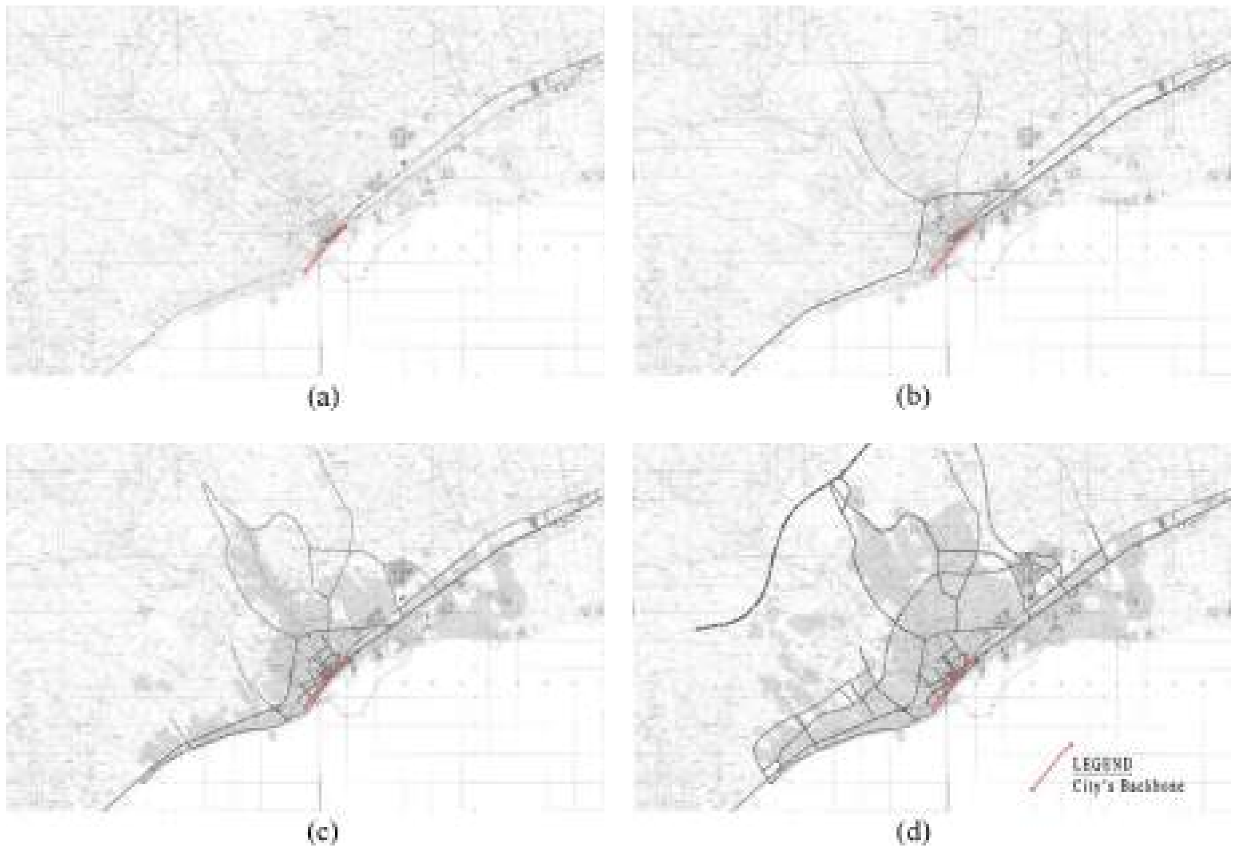


Figure 1. Historical development of Mersin and the CBD of the city **(a)** 1930s, **(b)** 1960s, **(c)** 1985s and **(d)** the 2000s (prepared by Z.S.Belge using 1/25.000 scaled recent base map from, base maps and reports prepared by the Municipality for planning activities from the archive of the Center for Mediterranean Urban Studies, Mersin University) (Belge, 2012).

center. The line originated from Customs Square, passed south of the Old Bazaar Area and extended to Mersin Bazaar. From there, it followed Atatürk Street, turned onto Silifke Street near the Atatürk Museum and ended at Müftü Stream. It then rejoined Atatürk Street via an alternative route through the military zone before returning to Customs Square. However, under the French Administration in 1921, the tram line was redeveloped from Customs Square to the Railway Station exclusively for freight transportation. In 1931, the entire tram line was dismantled and decommissioned (Develi, 1998). The disruption of the integrated road-railway-maritime network that sustained and strengthened Mersin's urban spine has had a dual effect: weakening both the historic city center's functionality and the spatial influence of the urban spine itself.

Over time, urban interventions led to significant changes in the city's spine. Due to land reclamation projects and the construction of new coastal roads, the Uray Street–Atatürk Street spine gradually shifted inland, weakening its connection with the harbour and shoreline. The development of new boulevards, parks and recreational areas altered the socio-spatial structure of the urban spine. Notably, the lack of both direct and indirect pedestrian connections between Uray Street and the harbour further reinforced this separation (Figure 2). The weakening connection between the urban spine and the city's maritime identity zones, particularly due to diminished pedestrian connectivity, has hindered the spine's capacity for organic growth and integration, thereby limiting its systemic influence on the city.

Developing from the 19th century onwards, Uray Street became Mersin's main spine as the first urban development axis linking the Railway Station to Customs Square. Over time, this axis gradually expanded westward along Atatürk Street, leading to linear urban growth. Eventually, Uray Street merged with Atatürk Street and Kışla Street, forming the city's linear spine.

As Krier (1979) pointed out, the urban spine contains high-image-value structures and focal points with diverse functions. However, over time, while some of these spaces have been preserved, others have been demolished and replaced with new buildings. This situation has directly influenced the impact of the urban spine on the city as a whole. In this section of the study, these spaces and their

Figure 2. Competition area and its immediate surrounding projects (Mersin Büyükşehir Belediyesi, 2021).

spatial components have been identified and the losses incurred have been documented. Through design decisions, the restoration of image values based on these losses aims to achieve physical, functional and social sustainability.

Upon initial examination of the urban spine, which is formed by Uray Street, Atatürk Street and Kışla Street, one observes that it features significant historical and commercial landmarks. To the east of Uray Street stand the Railway Station and the Latin Catholic Church, built in 1846. Moving westward, the Old Government House, Sursok Han and Taş Han, constructed in 1871, are prominent, while Azakhan, once opposite Sursok Han, was demolished in 1988. The Old Mosque, dating to 1870, remains intact. Uray Street also hosts Türkiye İş Bankası, T.C. Merkez Bankası and Garanti Bankası, reflecting its commercial significance. Atatürk Street begins at Hastane Street, where the Yoghurt Bazaar, now a park and the Metropol Skyscraper, a city landmark, are located. South of the Hastane-Uray intersection, Customs Square and Customs Pier once served as major trade and transport hubs but were replaced by Ulu Cami and Ulu Bazaar in the late 19th century. The historical port lay east of the city center, with shops lining the route between Customs Square and the Atatürk House/Museum. Opposite the museum stood Akkahve, a key social venue, now the site of the Mersin Metropolitan Municipality building. West of the museum, the former People's Garden, now Cumhuriyet Square, historically hosted cultural events and currently houses the Mersin Cultural Center, functioning as the People's House (Selvi Ünlü & Ünlü, 2008).

The former People's House now functions as a Cultural Center, accommodating the Mersin State Opera and Ballet. The Atatürk Statue establishes a spatial connection to Cumhuriyet Square, a significant public and ceremonial space framed by the Orthodox Church, the Cultural Center and the Governor's Mansion. Atatürk House visually complements the square from the east. The former People's Garden, once located south of the statue, was replaced by a coastal road following land reclamation, leading to the creation of Atatürk Park in the 1980s. Redesigned in the 1990s, Cumhuriyet Square remains largely underutilized outside major events.

Extending westward from Cumhuriyet Square, Atatürk Street, formerly known as Kışla Street, served as the main axis of the early 20th-century Çamlıbel Neighborhood. The street preserves several historic residences, including Chachati House, previously used as a kindergarten, along with the Police Department Lodgings and a bank. A widened section, known as Lovers' Park, is also located along this route. Tall palm trees define the street's perspective, while an eucalyptus grove marks the site of the former military barracks, designated as a Grade II Natural and Historical Site. Across Müftü Stream, the Ministry of Environment and Urbanization is redeveloping the former Tevfik Sırrı Gür Stadium site into the People's Garden, with a pedestrian bridge under construction to connect it to Atatürk Street (Mersin Büyükşehir Belediyesi, 2021). The visual elements of Mersin's urban spine are detailed in Figure 3.

Design Space, Problems and Solution Objectives

The competition site has been designated as the Çamlıbel District, extending from Cumhuriyet Square to Müftü

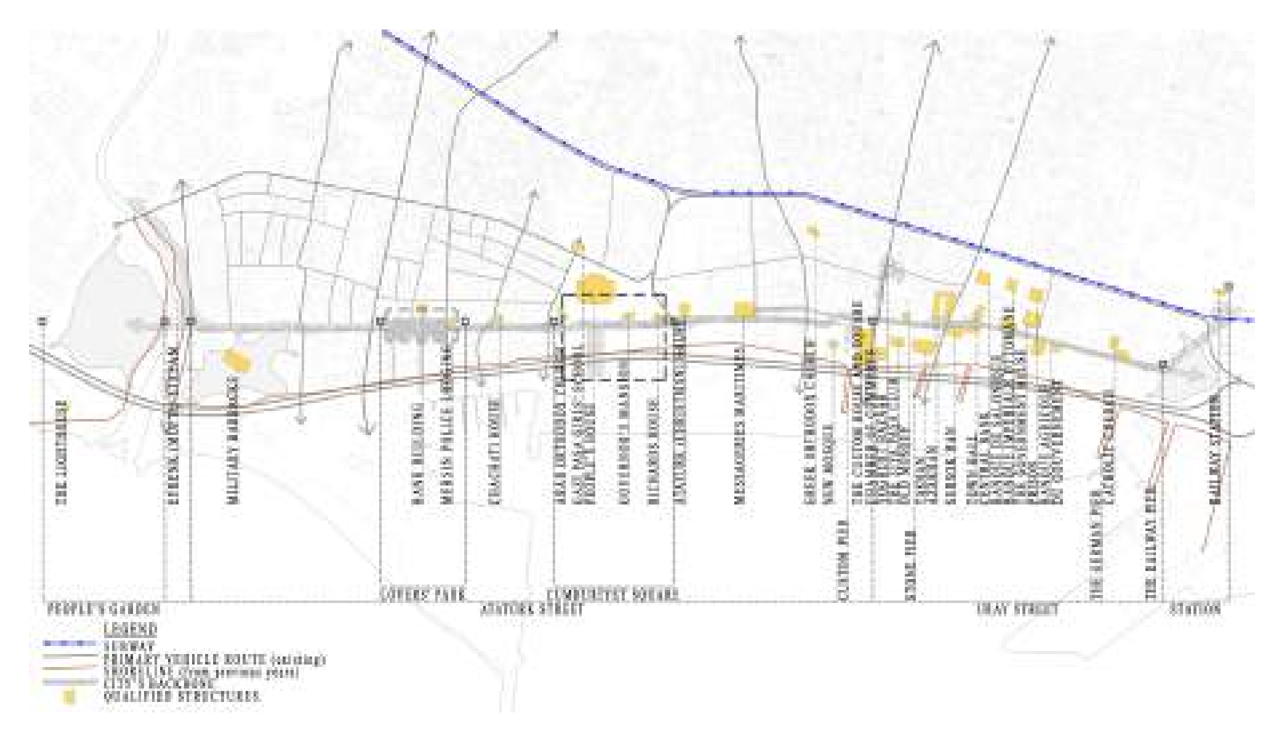


Figure 3. Urban image elements in in Mersin City's spine. Reproduced and adapted from (Selvi Ünlü & Ünlü, 2008; …).

Stream. To enable a multifaceted and contextual analysis of urban-scale problems, priority has been given to identifying and detailing the discontinuities along the urban spine stretching from Uray Street to Atatürk Street.

As a result of the studies, it has been determined that significant distortions have occurred in the authentic urban identity of Mersin due to rapid and unplanned urbanization. This deterioration is concentrated along the urban spine formed by the Uray-Atatürk Street axis, which constitutes the historical core of the city. In particular, with the construction of a new port, key urban focal points such as Customs Square, which was once integrated with the port, have lost their function, while the emergence of shopping malls has weakened the strong commercial fabric of the region. The integration of rail, road and maritime transportation, which once supported the city's infrastructure, has gradually deteriorated over time. Additionally, important public spaces along the spine (Customs Square, Yoghurt Bazaar, Cumhuriyet Square and Lovers' Park) have become disconnected, resulting in a loss of spatial continuity and urban cohesion.

In addition to these urban deteriorations, although Cumhuriyet Square, Lovers' Park and Atatürk Street exhibit diversity in terms of the city's physical, functional and social characteristics, the lack of systematic planning in intersecting areas and the presence of functions that do not support street and square usage have led to the emergence of undefined and fragmented spaces, which hinder pedestrian movement and disrupt holistic spatial order. Moreover, the absence of horizontal and vertical visual and spatial continuity has resulted in disconnected and unsafe passageways between the coast and the city. Pedestrian circulation is disrupted by physical and spatial barriers such as roadways, parked vehicles, elevation differences and other obstructions. Furthermore, the lack of sufficient shading elements reduces user comfort while the extensive use of concrete and asphalt surfaces contributes to the urban heat island effect. These constitute fundamental problems that negatively impact the active use of the urban spine, significantly diminishing the area's functionality and livability.

All these problems have collectively contributed to significant urban degradation along the spine. Physical, functional and aesthetic losses have accumulated, leaving key urban focal points dysfunctional and transportation networks fragmented. The once-cohesive continuity between focal points and streets has eroded, while pedestrian activity has declined noticeably. Furthermore, the functional and aesthetic integrity of spaces that connect the spine to vital urban features, including the sea and port, has significantly deteriorated. Most critically, some high-image-value spaces and their defining spatial elements have disappeared entirely, while others have suffered a marked decline in their perceived value, weakening the overall urban character. In light of the urban problems identified, it becomes crucial to contextualize the significance of Mersin's spine within established theoretical frameworks.

A comparative analysis against established theoretical frameworks positions Mersin's urban spine not as a simple thoroughfare, but as a critical, multi-functional element central to the city's structure. Its development appears organic, shaped by topography and history rather than formal planning, a phenomenon noted by Krier (1979). He views such spines as indicators of a civilization's level and symbols of political will, not just planning targets. This spine aligns with Bacon's (1967) definition of an urban spine as a movement system creating links between urban areas. It functions as a primary circulation corridor, dynamically shaped by the diverse commercial, administrative and cultural functions it contains. The structural analysis by Ekinci and Aktan (2017) provides a robust framework for understanding its qualities. Accordingly, Mersin's spine acts as a load-bearing element at the city's center of gravity, a connector between key zones and a hierarchical organizer of urban functions. It serves as a vital support line for daily life and defines the primary axis of the urban macroform. Furthermore, as emphasized by Mortazavi (1997) and Büyükcivelek (2012), the spine constitutes a rich urban formation not only through its socio-economic functions, which form the dynamic aspect of the city, but also through the abundance and diversity of public spaces that reflect its historical variety. These elements underscore the critical importance of the spine within the entirety of Mersin's urban structure. This role is crucial for urban image formation, aligning with Lynch's (1960) concept, as landmarks along the spine enhance the city's legibility and identity. In essence, Mersin's urban spine is a synthesizing element, integrating the theoretical qualities of load-bearing, connectivity, hierarchy and imageability to form a foundational component of the city's overall structure. This theoretical understanding provides the foundation for the proposed design strategies.

Within this framework, solution proposals have been developed to address these problems. For the rapidly growing and constantly changing city of Mersin, the most critical decision appears to be ensuring spatial continuity through strengthening, rehabilitating and reconnecting the existing urban spine. The primary strategy is to preserve and reinforce the existing urban spine to ensure continuity. Guided by this objective, streets and open green space systems have been conceptually enriched through historical references, cultural/artistic interventions, cultural landscapes and ventilation corridors, establishing a coherent urban identity. Furthermore, symbolic imagery has been strategically incorporated to enhance both the visual and functional legibility of urban space, while simultaneously strengthening the image value of the spine. To reinforce continuity along the spine, spatial integrity has been achieved through the creation of "opportunity corners" that emphasize nodal points and intersections, thereby enhancing the spine's image value. The overarching goal of this process is to enhance urban aesthetics and character, integrate historical, cultural, social, natural and touristic assets into urban life and develop a resilient and sustainable urban spine landscape through ecological restoration. Consequently, the proposed solutions fundamentally aim to reclaim Mersin's distinctive "urban spine" as a core element of the city's unique identity.

Analysis and Strengthening of the Urban Spine through Movement Dynamics

Establishing a robust movement system for the urban spine, thereby creating strong inter-district connectivity, has been identified as one of the design's key subsidiary objectives. To achieve this, the study implemented a multimodal analytical framework combining traditional personal observations with digital tracking methodologies. Specifically, GPS data collected in 2021 from the Strava application, a fitness tracking platform that monitors outdoor activities through smartphone location services, were analyzed alongside other datasets. Strava Metro provides anonymized, aggregated and normalized records from millions of user activities captured via smartphones and personal GPS devices (Griffin & Jiao, 2015). These passive and active forms of smartphone GPS tracking (SGT) have proven valuable for estimating visitor patterns and spatial behavior while requiring careful privacy considerations (Korpilo, Virtanen , & Lehvävirta, 2017).

To identify the city's most heavily used pedestrian routes, digital traces were cross-referenced with GSM system data. Through correlation with on-site observations, important focal points and connections were identified. Notably, these spatial nodes align precisely with significant historical buildings along the street, including the Church, Chachati House, the Police Department Lodgings and the Bank Building. This congruence between movement patterns and architectural heritage demonstrates how these focal points maintain their symbolic significance through historical continuity while serving vital functions in contemporary urban mobility networks. The integration of modern tracking technologies with traditional observational methods has thus provided a comprehensive understanding of both the physical and perceptual dimensions of the urban spine's functionality.

An analysis of the collected data reveals that pedestrian movement within the urban fabric is concentrated horizontally along İsmet İnönü Boulevard, İstiklal Street and the coastline, while it is concentrated vertically along Kuvayi Milliye Boulevard. Bicycle mobility, on the other hand, follows a different pattern from pedestrian movement and is primarily observed along Atatürk Street and Silifke Street, running parallel to the main axes (Figure 4).

An analysis of the research data identified disruptions in pedestrian flow, underutilization of circulation networks connecting the coast and city along the vertical axis and a lack of synergy among commercial, cultural, recreational

Figure 4. Main pedestrian and bicycle axes identified through user-recorded GPS (Global Positioning System) movement traces in Mersin city center. Reproduced and adapted from ECO.laud, 2021.

and food and beverage areas, despite their central location. In response, a pedestrianization strategy was implemented to enhance spatial cohesion, improve accessibility and support multifunctional urban use. Atatürk Street, with its strong pedestrianization potential, offers trade, culture, recreation and dining options within walking distance of the city center. This initiative not only fosters public health by increasing physical activity but also revitalizes street culture, transforming the area into a tourist attraction in Mersin, a city with significant tourism potential. The approach aims to advance the walkable city concept, extend pedestrian engagement and facilitate unrestricted movement through urban spaces. Additionally, inspired by historical documentation, bicycle use has been promoted as a sustainable, cost-effective and health-conscious mobility solution. The bicycle path from Atatürk Street was extended to Müftü Stream, connecting to the new People's Garden and further linked to Uray Street and the coastal road No. 4302, forming a circular network encompassing key urban nodes. To reinforce street culture for both pedestrians and cyclists, urban interventions have introduced diverse public spaces, including communal green areas and individual seating along the street, while maintaining spatial equity for commercial establishments.

Along the pedestrian and bicycle paths, adjustments in direction and continuity have been implemented to enhance street perception for both pedestrians and cyclists while fostering their active engagement with street life. This design strategy improves the user experience by facilitating the development of clustered green spaces, individual seating areas and various functional zones on both sides of the street. Additionally, these spatial interventions have contributed to a more balanced distribution of commercial units and ensured spatial equity, while optimizing the efficiency of public space utilization. In this context, integrating pedestrian and bicycle paths into street life constitutes a key design strategy that enhances urban mobility and fosters social interaction (Figure 5).

Vehicular traffic in the area is redirected to the horizontal axes of İnönü Street and Silifke Street through vertical connections. In terms of accessibility, it is recommended to repurpose the shopping mall into an indoor parking facility, while the green areas opposite the military lodgings are proposed to be converted into a parking garage. Additionally, within the pedestrianized zone along Atatürk Street, a designated safety strip has been established to accommodate vehicle use when necessary. In the section where the medical center is

Figure 5. Atatürk street pedestrianization project. Reproduced and adapted from ECO.laud, 2021.

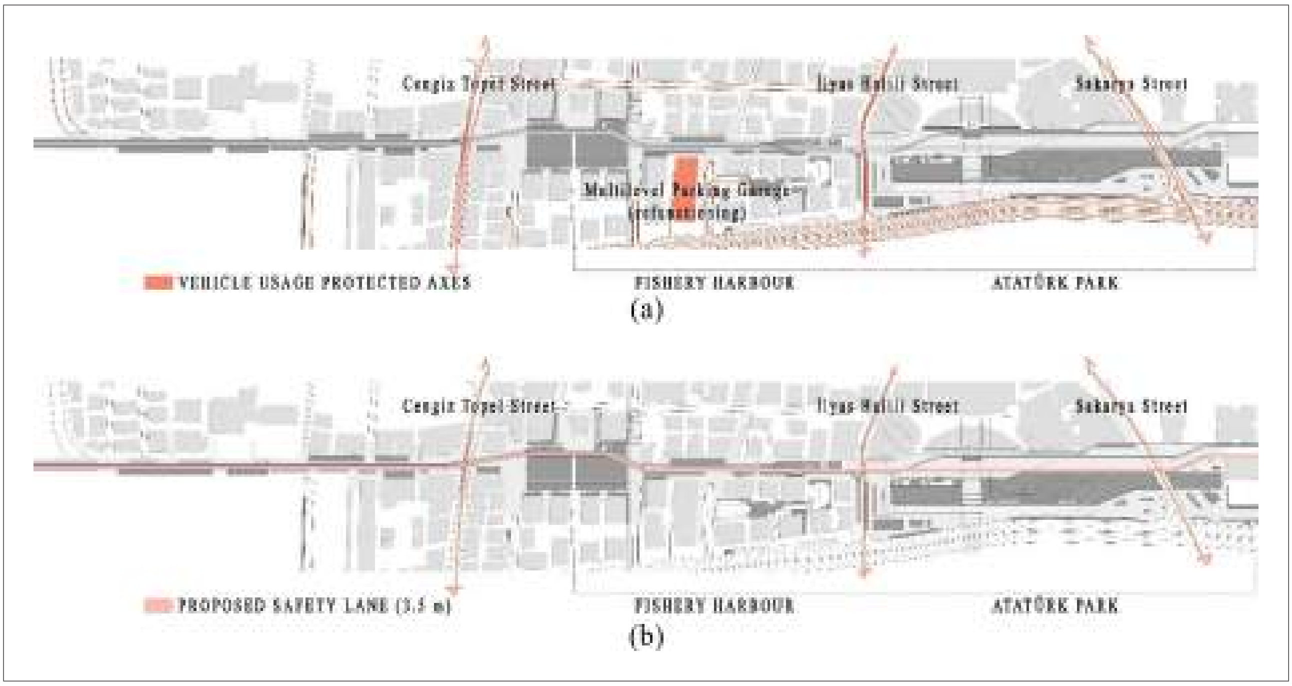


Figure 6. Protected roadway connections and proposed safety lane. Reproduced and adapted from ECO.laud, 2021.

located, vehicle access via the Cengiz Topel Street connection has been maintained. At the end of Atatürk Street, a bridge has been constructed across the Müftü Stream, providing direct access, particularly to the New People's Garden (Figure 6). All vertical connections have been integrated with the horizontal axis formed by the Uray-Atatürk Streets corridor, which constitutes the urban spine. The spine has been reinforced by incorporating pedestrian-priority measures and integrating alternative transportation systems, such as cycling, along its entire length.

Identification and Enhancement Of Focal Points And Connections Along The Urban Spine

The urban development of Mersin, initially influenced by the Latin Orthodox Church and the Catholic Church, has expanded beyond the Müftü Stream, which serves as the city's natural border today. In addition to this physical growth, the reorganization of Uray Street, the construction of the People's Garden and the creation of green areas along the coastline have transformed Cumhuriyet Square and Atatürk Street into a significant transition zone. In this context, the urban spine extends westward from Uray Street along Atatürk Street. While this expansion supports the healthy growth of the city, it also requires the seamless and harmonious integration of spatial components along the spine. As part of this study, four primary zones were identified: Atatürk Street 1st District, Lovers' Park, Atatürk Street 2nd District and Cumhuriyet Square. The design of these zones was elaborated to ensure physical, functional and ecological continuity (Figure 7).

Atatürk Street Zone 1 is designed with commercially oriented functions, comprising retail and food and beverage units, thereby ensuring commercial continuity along the street while extending commercial activity and urban vibrancy up

Figure 7. Sub-areas of the competition area. Reproduced and adapted from ECO.laud, 2021.

to the Müftü Stream. In the final segment, which extends to the Müftü Stream and where educational buildings are concentrated, commercial units such as book cafés and food and beverage spaces are proposed to cater to student needs.

Lovers' Park integrates cultural, artistic and recreational functions, including bookstores, cafes and food and beverage units, seamlessly connected to the beach and surrounding residential areas. This integration strengthens the link between the fisherman's shelter, the coastline and the broader urban fabric, reinforcing the park's place memory. The design preserves historical traces while emphasizing greenery, transforming the space into a vibrant cultural and artistic hub. Enriched with musical and artistic activities, the park attracts both residents and tourists by offering diverse functions and high-quality spaces. However, despite its historical significance, the park currently serves as a fragmented and unstructured parking lot. The proposed design aims to restore its identity by reinstating its dense green environment and reinforcing the strong natural border formed by trees. Originally conceived as a tranquil retreat, this function is preserved while enhancing the park's spatial value through strategic interventions. A sequence of curated spaces has been introduced between the cultural and artistic zones near the bank building, the police department lodgings and Lovers' Park, establishing a setting where nature and art intertwine. Additionally, commercial spaces such as sales units, cafes, bookstores and food and beverage establishments are incorporated, allowing public engagement in trade (Figure 8).

Tourism-oriented commercial areas have been planned along the axis that connects Cumhuriyet Square via Road 4302 in the 2nd District of Atatürk Street. In this context, shops selling local goods, offices organizing sightseeing tours and businesses offering accommodation and car rental services have been designated. Additionally, the area's tourism appeal has been enhanced by designing food and beverage venues within corner shops, which are strategically positioned to blend with green areas and provide sea views (Figure 9).

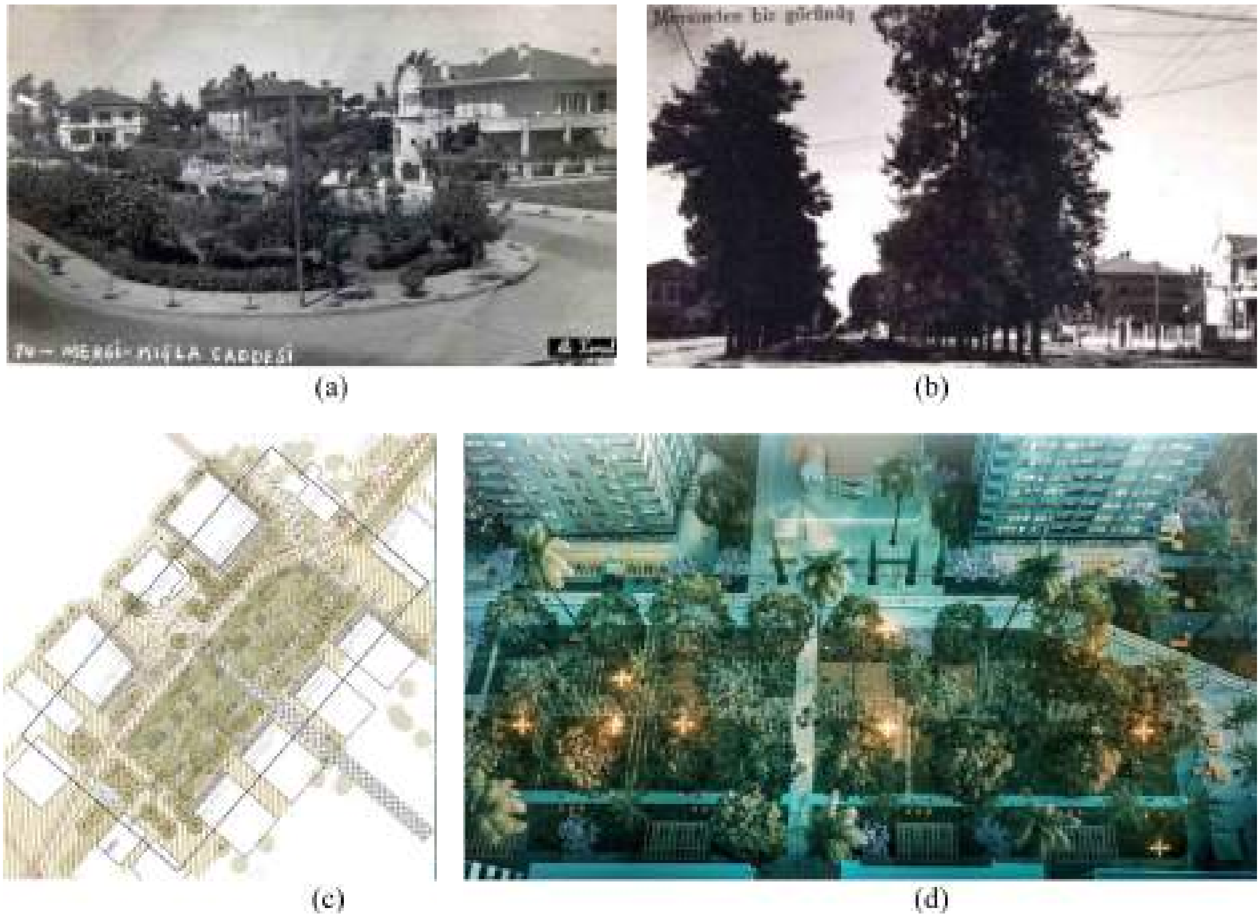


Figure 8. **(a)** Historical view of Mersin Kışla Street (Agah Müzayede, 2022), **(b)** Historical view of Lovers' Park (Mekânda Adalet Derneği, 2019), **(c)** Proposed design plan for Lovers' Park (ECO.laud, 2021), **(d)** Aerial perspective of the proposed Lovers' Park (ECO.laud, 2021).

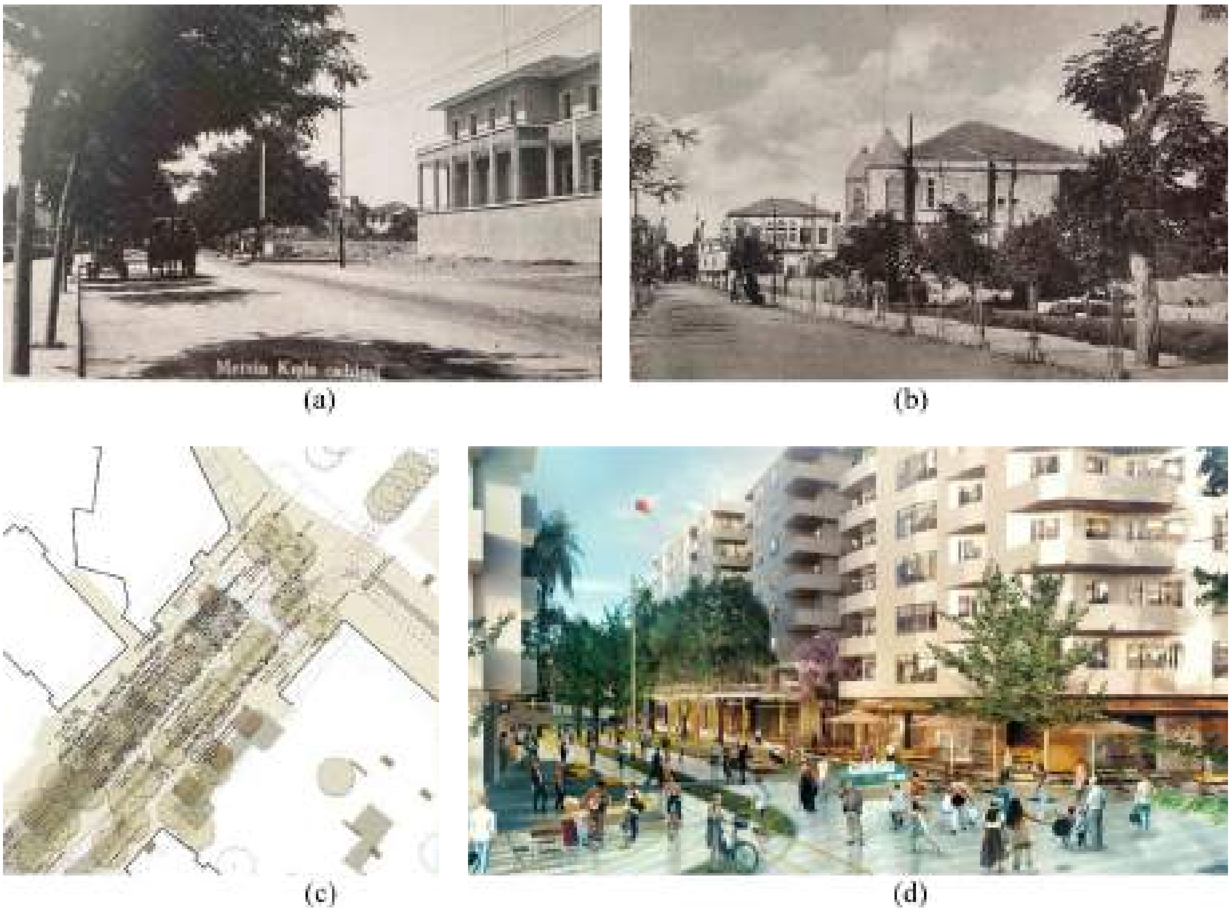


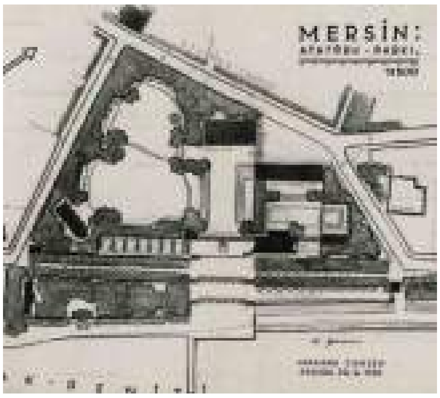
Figure 9. **(a)** Historical view of Mersin Kışla Street (Selvi Ünlü & Ünlü, 2008), **(b)** Historical view of Atatürk Street (Selvi Ünlü & Ünlü, 2008), **(c)** Proposed design plan for Atatürk Street (ECO.laud, 2021), **(d)** Aerial perspective of the proposed Atatürk Street (ECO.laud, 2021).

At Cumhuriyet Square, the vertical axis, which is defined by the People's House and Atatürk Statue and extends towards the coast and the horizontal axis extending from Uray Street constitute the primary elements shaping pedestrian circulation within the square. A key objective is to emphasize the People's House, a significant landmark in the city's skyline, by ensuring its harmonious integration with the surrounding greenery. Historically, the summer cinema (Parthe Cinema), situated within the People's Garden, served as a focal point for social activities such as concerts, garden parties, dance events and dining gatherings. It also hosted official celebrations following the proclamation of the Republic. This historical and cultural heritage has been reinterpreted for contemporary use by enriching the square with multi-functional spaces, such as an amphitheater, a free activity meadow and playgrounds under trees, to accommodate diverse user needs and activities. Given Mersin's hot climate, the square has been designed with more greenery and shaded areas, as hard surfaces contribute to the heat island effect. The goal is to mitigate this effect, preserve the square's identity as a central gathering place and enhance its role as a vibrant public space beyond ceremonial events (Figure 10).

The urban spine features nodes of distinct character. While Cumhuriyet Square functions as a ceremonial ground, Lovers' Park holds the potential to be a significant recreational area for the city. Atatürk Street, which connects these nodes, plays a vital functional and social role. Consequently, the spine is strengthened not merely as a physical connector but also through its incorporation of functional integrity.

Ensuring Functional Continuity on the Urban Spine

The functions proposed throughout the street provide longer visiting times, aiming for functional diversity and high-quality outdoor spaces. In addition, the aim is to increase the interface areas between citizens and outdoor spaces, thus giving citizens more chances to experience the city. In the distribution of functions, commercial places for eating and drinking are suggested at iconic locations that are remarkable for the user with existing historical buildings. Asiklar Park is envisioned to be a focal point where



(a)

(b)

(c)

(d)

Figure 10. **(a)** The 1936 Hermann Jansen Plan for Mersin Atatürk Park (Selvi Ünlü, 2016), **(b)** The historical appearance of Mersin People's House (Bozkurt & Geylani, 2017), **(c)** Proposed design plan for Cumhuriyet Square (ECO.laud, 2021), **(d)** Aerial perspective of the proposed Cumhuriyet Square (ECO.laud, 2021).

Figure 11. Proposed Functional Zoning of the Project Area. Reproduced and adapted from ECO.laud, 2021.

culture, art, recreation and trade opportunities are offered. In this area, diverse functions such as resting, entertainment, reading, eating and drinking are combined. Additionally, urban interfaces have been enhanced to strengthen the engagement between residents and outdoor spaces, fostering greater interaction between users and the urban environment (Figure 11).

The intersection of the identified connections and focal points with the historical buildings of the street, namely the Church, Şaşati House, Police Departments Lodging and Bank Building, enabled these focal points to define their symbolic significance through the traces of History. Chachati Evi, is used as a kindergarten today and has a place in the public memory as Micky Mouse. The building was re-functioned as a “Children’s Library” that remained special for children, while serving more participants. Thus, on the one hand, the place of the building in the collective memory was preserved; and on the other hand, the children would experience an architecturally rich and historical building, spreading the awareness of conservation.

In order to support the artistic and cultural structure of the city, the aim is to use the Police Department Lodgings for ballet, dance and music courses and the Bank Building to serve as a space for painting and sculpture workshops and courses. In addition, the building between them is designed as a multi-purpose space that supports open-air events such as exhibitions and shows, ensuring continuity in social interactions and connecting social activities (Figure 12). The impact of the urban spine has been enhanced by reinforcing the visual prominence of its high-image-value historical structures, notably the historic Şaşati House, Police Departments Lodging, Bank Building, Community Center and Orthodox Church.

RESULTS

The urban spine is designed to serve both the entire city and specific districts, fulfilling roles such as structural support, connectivity, hierarchy formation and spatial cohesion. Especially in rapidly growing cities such as Mersin, this spine is recognized for ensuring a seamless transition from the past to the future by integrating seamlessly with the urban fabric. An examination of Mersin reveals that its urban spine, shaped by spatial dynamics, has evolved into a structure that now triggers new spatial dynamics and determines the city’s developmental direction. The city’s relationship with the sea, its topography and its strong horizontal interaction with other coastal cities have ensured this development occurs along the spinal axis. The initial spine structure formed by its port city origins and the city’s growth integrated with this spine are clearly discernible. In Mersin, it has been observed that this spine, which extends from Uray Street to Atatürk Street and expands westward, continues to evolve and expand, influencing both horizontal and vertical urban axes.

Figure 12. Proposed street descriptions for Lovers’ Park and its surroundings integrating culture, arts and recreation functions.

Specifically in Mersin, the urban spine defined by Uray-Atatürk Street has served as the commercial, administrative, cultural and social spine of the city center from the past to the present day. Mersin's urban spine possesses a versatile character that interconnects different functions. This is evident in the recreational focal spots (Lovers' Park, etc.), ceremonial areas (Cumhuriyet Square, etc.) and rich public formations located along the same axis. Furthermore, strong connections between commercial, social and cultural functions are observed along the spine. Although new horizontal and vertical connections have been introduced, the spine has maintained its integrity. Beginning at Uray Street, this spine expands westward, establishing a functional hierarchy encompassing commercial, religious and cultural elements. Mersin's status as a port city has contributed to the formation of a linear urban spine along the horizontal axis, further reinforcing this spatial structure. Throughout the city's transformation, this spine, extending from the port inward, has emerged as a crucial zone preserving Mersin's historical memory, mirroring its cosmopolitan character and accommodating diverse functions, including religious, commercial, entertainment and accommodation purposes. It is understood that urban spines are not merely transportation corridors but also accommodate a stock of buildings with varied functions and diverse open public spaces. This multifunctionality further enhances the spine's impact on the entire city. In Mersin, alongside historic public spaces representing the city's public realm, new recreational areas are observed to be integrated into this system. The urban spine formed by Uray-Atatürk Street is instrumental in shaping the city's identity through its historical, social and cultural spaces that embody diverse aesthetic perspectives and dynamic social interactions. Additionally, as it is integrated with various transportation networks, including railway and maritime systems, this spine establishes a robust mobility network within the city.

The jury's first-prize evaluation confirms that the study effectively addressed the core requirements of the competition, including social inclusivity, cultural revitalization, accessibility and sustainable material use, through a spine-oriented design strategy. The clarity of the spatial system, the integration of urban layers and the contextual sensitivity reflect the theoretical premise of the urban spine as a framework that organizes movement and space while generating meaning and identity. The study therefore offers a validated example of how theory can be applied in complex urban conditions, demonstrating the value of theory-driven design in contemporary planning practice.

These findings indicate that the urban spine is a significant determinant of the city's development trajectory. Initially functioning primarily as a transport connector following Mersin's establishment as a port city, the urban spine has gradually acquired functional diversity through the incorporation of additional uses. Furthermore, by hosting historical structures that represent cultural continuity and a deep-rooted past, the urban spine has played a key role in preserving the city's integration with its historical identity. However, this critical role has recently come under pressure due to rapid urban transformation.

Amid rapid urbanization, land reclamation efforts and port relocation in Mersin, the influence of the existing urban spine on the overall urban fabric has diminished. The effects of this transformation are distinctly observable on Atatürk Street, a key segment of Mersin's urban spine. A major issue in the area is that the historic Uray Street-Atatürk Street spine, which embodies the city's physical, social, cultural and political heritage, serves as a connective axis linking public spaces and buildings within a structured urban framework that ensures spatial balance. However, it lacks adequate physical, functional and social integration with newly developed urban areas.

Connecting the Urban Spine with Enhanced and Continuous Pedestrian Mobility

An analysis of movement dynamics revealed that the once-strong pedestrian flow along the Atatürk-Uray Axis has gradually diminished, disrupting the continuity of the urban spine. Pedestrian connections were identified as weak not only along the east-west axis but also in the north-south direction. Therefore, a comprehensive pedestrianization strategy was implemented along Atatürk-Uray Street, additionally supported with dedicated bicycle lanes. Furthermore, overpasses, bridges and pedestrian crossings were proposed to enhance connectivity between Historic Uray Street and the recently developed People's Garden and Atatürk Park.

Maintaining the Continuity of Key Focal Points and Connections on the Urban Spine

Atatürk Street, which extends from Uray Street and hosts numerous historical sites forming the city's core, serves as a crucial link within the newly emerging urban fabric. This connection holds significant potential both in its immediate context and broader urban network. The continuity of the urban spine has been reinforced by integrating this area, which accommodates a mix of commercial, cultural and recreational functions while possessing high public potential, through enhanced horizontal and vertical linkages. Continuity and spatial integrity have been preserved by safeguarding its historical significance and physical legacy within the city's collective memory.

Maintaining Functional Continuity on the Urban Spine

The goal is to preserve the strong commercial character inherited from Uray Street while ensuring harmony with the area's dynamics. Through enhanced interaction with key public spaces such as Cumhuriyet Square and Lovers' Park, high-quality open urban spaces offering diverse functionalities have been designed. Thus, the engagement between residents and public spaces has been strengthened, revitalizing the area's vibrancy.

Findings indicate that the urban spine plays a crucial role in shaping urban identity and ensuring urban continuity. Its functions, including providing structural support, connectivity, balance, reinforcement and hierarchical organization, should be comprehensively analyzed from a design perspective to address both micro and macro-scale urban contexts. The spine is not merely a conduit for movement but also an integrative system of physical, socio-cultural and economic networks. This study demonstrates that strengthening the urban spine is not merely a theoretical concept but also a practical and implementable strategy. Ultimately, this study concludes that protecting and developing the urban spine provides significant benefits for sustainability, spatial cohesion and balanced urban growth in rapidly expanding cities.

Although the concept of a "spine" is associated with different ideas across disciplines, it is fundamentally defined as a central axis formed through continuity. According to Ekinci and Aktan (2017), a spine possesses qualities such as load-bearing, connectivity, establishing hierarchy, providing support and forming an axis. At the urban scale, Bacon (1967) characterized the urban spine as a movement system creating links between urban areas defined by spatial elements, while Krier (1979) viewed it as a political force and a symbol of civilization; traits observable in the character of Mersin's urban spine.

As noted by Krier (1979), the spine in Mersin is not a planning target but rather a result of the city's development and topography. Mersin's urban spine, as indicated by Bacon (1967), not only houses diverse functions but also defines a robust movement system generated by these functions. As emphasized by Mortazavi (1997) and Büyükcivelek (2012), the spine represents a rich formation not only through its socio-economic functions, which constitute the city's dynamic aspect, but also through the number and diversity of public spaces embodying its historical variety. These elements underscore the spine's critical importance within the entirety of Mersin.

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REFERENCES

Adıyeke, A. N., & Adıyeke, N. (2004). Modernleşmenin doğurduğu kent: Mersin [The city born from modernization: Mersin]. In F. Özdem (Ed.), *Sırtı Dağ Yüzü Deniz: Mersin* (pp. 69–89). Yapı Kredi Yayınları.

Agah Müzayede. (2022). *Efemera-Kitap-Fotoğraf-Obje Müzayedesi* [Ephemera-Book-Photo-Object Auction]. Retrieved Jan 9, 2025, from https://www.agahmuzayede.com/urun/4865117/mersin-kisla-caddesi

Akkaya, Y. (2004). 19. yüzyıldan 20. yüzyıla Mersin ekonomisi [Mersin economy from the 19th to the 20th century]. In F. Özdem (Ed.), *Sırtı Dağ Yüzü Deniz: Mersin* (pp. 335–349). Yapı Kredi Yayınları.

Bacon, E. N. (1967). *Design of cities*. Thames & Hudson.

Belge, Z. S. (2012). Increasing walkability capacity of historic city centers: The case of Mersin [Master's thesis]. Middle East Technical University.

Bozkurt, İ., & Geylani, N. (2017). Erken Cumhuriyet döneminde boş zamanı geçirme alışkanlıkları ve sosyal mekânlar: Mersin örneği [Leisure time habits and social spaces in the early Republican period: The case of Mersin]. *Pamukkale Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, (27), 346–359. https://doi.org/10.30794/pausbed.414977

Büyükcivelek, A. B. (2012). Kentsel omurga / kent omurgası [Urban backbone / city spine]. In M. Ersoy (Ed.), *Kentsel Planlama - Ansiklopedik Sözlük* (pp. 138–139). Ninova Yayıncılık.

Develi, Ş. (1998). *Akdeniz'de inci kent: Mersin* [Pearl city in the Mediterranean: Mersin]. Mersin Büyükşehir Belediyesi.

Durak, S. (2006). 1929 dünya ekonomik buhranının Mersin limanı üzerine etkileri [The effects of the 1929 global economic depression on the Mersin port] [Master's thesis]. Mersin Üniversitesi.

Ekinci, E., & Aktuğlu Aktan, E. Ö. (2017). Kent planlamada omurga kavramı ve tarihi yarımada örneği [The concept of backbone in urban planning and the historical peninsula example]. *İdealKent, 8*(22), 483–509.

Griffin, G. P., & Jiao, J. (2015). Where does bicycling for health happen? Analysing volunteered geographic information through place and plexus. *Journal of Transport & Health, 2*(2), 238-247. https://doi.org/10.1016/j.jth.2014.12.001

Güncel Türkçe Sözlük. (2025). *Türk Dil Kurumu Sözlükleri* [Current Turkish Dictionary]. Retrieved Jan 9, 2025, from https://sozluk.gov.tr/

Hisarlı, G. (1988). Mersin kenti açık ve yeşil alanları üzerinde bir araştırma [A study on open and green spaces in the city of Mersin] [Master's thesis]. Çukurova Üniversitesi.

Korpilo, S., Virtanen, T., & Lehvävirta, S. (2017, January). Smartphone GPS tracking—Inexpensive and efficient data collection on recreational movement.

Landscape and Urban Planning, 157, 608–617. https://doi.org/10.1016/j.landurbplan.2016.08.005

Krier, R., & Rowe, C. (1979). *Urban space*. Academy Editions.

Lynch, K. (1960). *The image of the city*. The MIT Press.

Mekânda Adalet Derneği. (2019). *Çamlıbel Yürüyüş Haritası* [Çamlıbel Walking Map]. Retrieved Jan 9, 2025, from https://mekandaadalet.org/wp-content/uploads/2021/02/mersin_camlibel8_SON.pdf

Mersin Büyükşehir Belediyesi. (2021). *Cumhuriyet Meydanı ve Atatürk Caddesi Çamlıbel Kentsel Tasarım Yarışması* [Republic Square and Atatürk Street Çamlıbel Urban Design Competition]. Retrieved Jan 9, 2025, from https://yarismalar.mersin.bel.tr/yarisma-kunyesi24/

Mortazavi, S. M. (1997). The boulevard as a tool in city planning [Master's thesis]. Middle East Technical University.

Selvi Ünlü, T. (2007). *19. Yüzyılda Mersin'in kentsel gelişimi* [Urban development of Mersin in the 19th century]. Mersin Üniversitesi Yayınları.

Selvi Ünlü, T. (2016). Mersin'in Cumhuriyet modernleşmesi sürecini bir eğitim yapısı üzerinden okumak: Mersin Lisesi (Tevfik Sırrı Gür Lisesi) [Reading the Republican modernization process of Mersin through an educational structure: Mersin High School (Tevfik Sırrı Gür High School)]. *Megaron, 11*(3), 449–466.

Selvi Ünlü, T., & Ünlü, T. (2008). *İstasyon'dan Fenere Mersin* [Mersin from the station to the lighthouse]. Mersin Ticaret ve Sanayi Odası Yayınları.

Strava, I. (2021). *Global Heatmap* [Global Heatmap]. Strava. Retrieved Jan 9, 2025, from https://www.strava.com/maps/global-heatmap

Ünlü, T. S. (2009). Bir iskeleden liman kentine: Doğu Akdeniz'in önemli bir limanı olarak on dokuzuncu yüzyılın ikinci yarısında Mersin'de mekânsal gelişim [From a pier to a port city: Spatial development of Mersin in the second half of the 19th century as an important port of the Eastern Mediterranean]. *Planlama Dergisi, 3*(47), 5–26.

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Article

Exploring the transition from domicentric to heterocentric environments: Children's cognitive thresholds in urban spaces

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ABSTRACT

Using the cognitive mapping method, this research examines the spatial and cognitive factors shaping children's perceptions of the journey from home to school and interprets the results from the perspective of the architectural discipline. Conducted with 52 first-grade students (22 girls, 30 boys) from a primary school in Istanbul, it analyzes children's drawings through mapping typologies and Kevin Lynch's five elements-paths, edges, districts, nodes and landmarks (1960). Drawing on Piaget's theory of cognitive development (1954) and Hart & Moore's concept of spatial thresholds (1973), the method integrates qualitative interpretation of drawings with quantitative Pearson's chi-square testing, situating the study within broader research on mobility, gender, and environmental perception. Three mapping typologies were identified: scattered, linked, and patterned. Most children produced scattered maps, suggesting fragmented spatial understanding, whereas those living closer to school included more paths in their drawings, highlighting the role of proximity in spatial perception. Some gender-related patterns were observed within this sample (n=52) for example, relatively more structured maps among some girls and more scattered layouts among some boys. Given the small sample and the limited power of Pearson's chi-square tests with sparse categories, these should be treated as exploratory, sample-specific tendencies rather than generalizable effects. Beyond these statistical tendencies, the analysis of developmental thresholds revealed that, most children demonstrated emergent heterocentric spatial perception features at 6–7 years (within the domicentric stage, early signs only), corresponding to meso-environments, with fewer displaying egocentric (micro-environment) or Euclidean (macro-environment) perspectives. Given that the sample is 6–7 years old, heterocentric indicators are interpreted as early/emergent features rather than full stage attainment. These results highlight the transition from domicentric to heterocentric spatial understanding. Ultimately, the study provides insights into the interplay of spatial cognition, gender, and proximity in shaping children's maps, offering practical implications for designing child-oriented urban and architectural environments that foster spatial understanding and cognitive development.

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INTRODUCTION

The home and its surrounding environment contribute to human emotional and psychological well-being, serving as both shelter and foundation for early development. The home space represents a critical area for children in the sensory-motor stage, the first stage of Piaget's theory of cognitive development (1954). Children begin to understand and interact with their environment at this stage. This progression and transition highlights the importance of an interdisciplinary approach that integrates environmental psychology, sociology, pedagogy, and architecture, as architecture plays a key role in meeting children's evolving needs and ensuring their seamless integration with their environment. Since the 1960s, both architecture and psychology have examined how spatial organization and environmental design affect children's cognitive and social development. Both disciplines provide complementary perspectives on the interaction between design and human development, revealing how physical environments influence cognitive and social processes, particularly in childhood development. Foundational sociological concepts such as Cooley's (1909) distinction between primary and secondary environments and Tönnies's (1887) notions of *Gemeinschaft* and *Gesellschaft* provide the groundwork for understanding human-environment relations. Building on these sociological foundations, environmental psychology further explains how spatial organization influences behavior. Subsequent theories - including Hall's (1966) and Altman's (1975) explorations of personal space, Bronfenbrenner's (1979) ecological systems framework, and Oldenburg's (1989) theory of the "third place"- further elucidate how spatial contexts shape social interaction, behavior, and a sense of belonging. These foundational theories also implicitly emphasize the importance of designing environments that nurture children's cognitive and social development.

The home, as the primary environment, forms the foundation of children's earliest social experiences and identity development. Within Piaget's (1954) cognitive development framework, a secure environment supports emotional attachment and the emergence of self-awareness. Expanding on this view, Hart and Moore (1973) conceptualized spatial cognition through four developmental thresholds: egocentric (0–3), domicentric (3–8), heterocentric (8–12), and Euclidean (12+). These stages illustrate the progression from immediate, home-centered experiences toward broader and more abstract spatial systems. In this study, Piaget's cognitive stages (pre-operational 2–7; Concrete operational 7–11; Formal operational 11+) and Hart & Moore's spatial stages are treated as distinct but complementary frameworks. The participant group (ages 6–7) corresponds primarily to the late pre-operational/early Concrete and domicentric stages; any heterocentric elements observed are considered early or emergent rather than fully realized characteristics.

As children gradually move beyond the familiarity of the home environment, the school emerges as the first social extension of their spatial world, marking the beginning of their interaction with structured public spaces. Schools, as secondary settings, represent children's first experiences with broader social structures and norms. Tönnies' (1887) conceptualization of the transition from natural will (home space) to rational will (school space) emphasizes the critical role of this process in children's cognitive and social development and their interactions with public spaces. Piaget's model of cognitive stages provides the foundation for understanding how children perceive and represent their environments.

Lynch (1960) introduced the basic concepts of paths, edges, nodes, districts, and landmarks in environmental orientation, which form the basis of spatial mapping.

Another contribution about the subject, Appleyard (1970) categorized children's maps into scattered, linked, and patterned types., while Ladd (1970) classified children's neighborhood maps as graphic, schematic, connected, and nodal maps. Hart and Moore (1973) described spatial development through egocentric, domicentric, heterocentric, and Euclidean stages.

Later research (İmamoğlu, 1979; Herman, 1980; Doherty & Pellegrino, 1985) emphasized age, socioeconomic context, and environmental exploration as key influences on spatial awareness.

Since the 2000s, research has increasingly explored how children's spatial cognition interacts with environmental, social, and individual variables such as mobility, gender, socioeconomic background, and environmental legibility. These studies collectively emphasize that cognitive mapping is shaped by freedom of movement, family support, and neighborhood characteristics, highlighting the dynamic relationship between spatial experience and development (see also Ünlü & Çakır, 2002; Risotto & Tonucci, 2002; Yavuzer, 2003; Öztürk, 2009; Çanakçıoğlu, 2011; Türel & Gür, 2019; Burkut & Köseoğlu, 2022; Coşkun & Kaymaz, 2022).

Cross-cultural and contextual perspectives have further enriched this field, revealing how social belonging, cultural identity, and environmental familiarity influence children's representations of space (see also Thommen et al., 2010; Mohsenin, 2011; Koç, 2012; Park & Kim, 2012; Damayanti & Kossak, 2016; Gillespie, 2010; Öztürk, 2015; Den Besten, 2017; Baksi, 2018; Rzhanova et al., 2020; Seyhan, 2021; Lowrie et al., 2022).

Building upon these cumulative findings, this study examines the cognitive mapping abilities of first-grade primary school students in Istanbul during their daily journeys from home to school and how these abilities influence spatial thinking thresholds. The research draws on the cognitive mapping typologies of Appleyard (1970), Lynch (1960), and Downs & Stea (1973), as well as Piaget's (1954) theory of cognitive development. The environments on the routes that children regularly use between home and school are analyzed, from housing to creating child-centered spaces and even implementing urban-level planning concepts.

Within the continuum of primary (home) and secondary (school) environments, this study investigates how these domains are perceived and represented in children's spatial cognition. The question thus arises as to how these settings manifest themselves in the child's perceptual world. Building on Hart and Moore's (1973) spatial organization stages, this study investigates how the boundaries of primary and secondary settings are interpreted within egocentric, domicentric, and heterocentric stages, and how these perceptions relate to Piaget's (1954) age-based developmental stages.Within this framework, variables such as gender, mode of transportation, and school proximity are examined for their influence on children's spatial perception. Supported by Tönnies' (1887) distinction between Gemeinschaft (community) and Gesellschaft (society), the study explores how spatial design can facilitate children's transitions between home and school environments. This interdisciplinary approach aims to contribute to the development of inclusive and supportive spatial models that align with children's cognitive and social growth.

By addressing these relationships empirically, the study not only clarifies children's perceptual thresholds but also contextualizes them within the broader framework of environmental design. Analyzing children's heterocentric spatial perceptions might offers a foundation for understanding the relationship between developmental psychology and architectural design. Despite extensive research on children's cognitive development and spatial mapping, further work is needed to examine diverse cultural and urban contexts and to translate findings into child-centered design strategies.

While previous studies have explored children's transitions from domicentric (home-centered) to heterocentric (urban and social) spaces, few have connected these shifts to architectural or urban design practice. Addressing these gaps, this study aims to deepen the understanding of the spatial and environmental factors that shape children's cognitive development. Integrating Tönnies's (1887) Gemeinschaft–Gesellschaft framework, the study examines how spatial design can support children's transitions between community (home) and society (school).

THEORY

The 6-7-year-old age group examined in this study is positioned at the intersection of Piaget's pre-operational and concrete operational stages and on the threshold of Hart & Moore's domicentric and heterocentric stages. Therefore, this group bears traces of both home-centered perceptions and early urban environmental sensitivities.

This framework is based on Piaget's (1954) theory of cognitive development and Hart and Moore's (1973) stages of spatial perception. According to Piaget, children interact with their environment through knowledge and experience and progress through four developmental stages. Children's cognitive development is influenced by biological, cultural, and experiential factors; adaptation processes occur through assimilation and adaptation (Ormrod, 2013; Wadsworth, 2015). The age categories used in this study are summarized in the Table 1 below:

Standardization Note: Piaget and Hart and Moore are distinct frameworks and are not treated as equivalent. The 6–7 year old group examined in this study is positioned at the intersection of Preoperational/Concrete (Piaget) and on the threshold of Domicentric (Hart–Moore), with emergent heterocentric features possible but not assumed as full stage attainment.

For consistency, scale references are standardized as follows: Egocentric & Domicentric=micro; Heterocentric=meso; Euclidean=macro.

Figure 1 illustrates the four spatial stages of environmental cognition- egocentric (0-3 years), domicentric (3-8 years), heterocentric (8-12 years), and Euclidean (12+ years) as conceptualized by Hart and Moore (1973) building on Piaget's developmental framework.

Building on previous section, the transition from domicentric to heterocentric perception, reflecting children's early movement from home-centered to city-oriented spatial understanding. This shift also mirrors a broader transition from community to society.

Table 1. Cognitive development and spatial perception stages according to Piaget (1954) and Hart & Moore (1973)

Hart and Moore's Stages	Piaget's Cognitive Stages	Key Spatial and Cognitive Traits
Egocentric Space (0-3)	Sensorimotor (0-2)	Immediate bodily interaction; no external references.
Domicentric Space (3-8)	Preoperational (2-7)	Home-centered awareness is characterized by early symbolic thought.
Heterocentric Space (8-12)	Concrete Operational (7-11)	This involves interaction with larger environments and logical reasoning.
Euclidean Space (12-14)	Formal Operational (12+)	Abstract reasoning; structured and metric understanding.

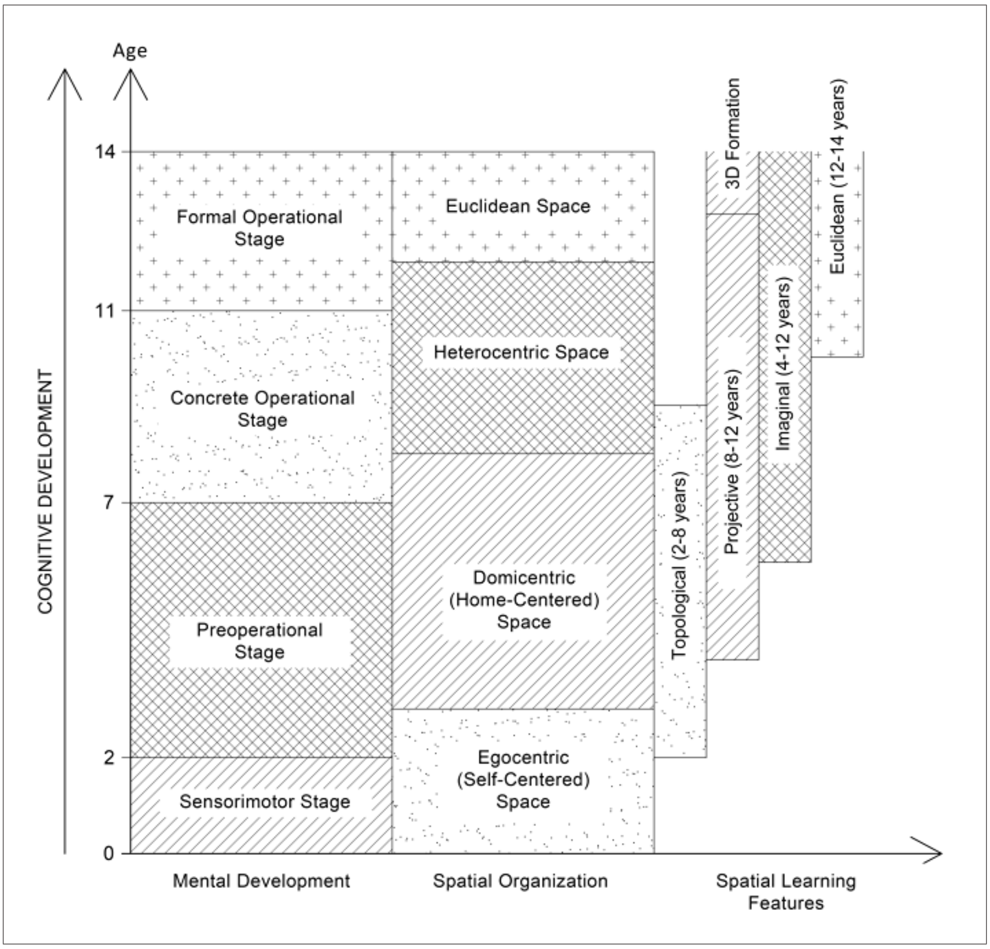

Figure 1. Mental and spatial relationship in the child's perception (Ünlü & Çakır, 2002; adapted from Hart & Moore, 1973).

The literature highlights age, gender, socioeconomic status, and transportation in shaping spatial perception. Studies show that walking enhances spatial awareness (Herman, 1980), mobility fosters better mapping skills (Risotto & Tonucci, 2002), and sociocultural context influences environmental cognition (Gillespie, 2010; Nikitine-Den Besten, 2010). Research also indicates gender differences in spatial tasks (Ünlü & Çakır, 2002; Rzhanova et al., 2020) and links socioeconomic status to differing preferences and cognitive responses to indoor vs. outdoor environments (Baksi, 2018; Öztürk, 2009, 2015).

Within these contextual influences, cognitive maps serve as, cognitive maps serve as key indicators of children's spatial understanding. Appleyard (1970) categorized them as scattered, linked, or patterned. Empirical studies (e.g., Park & Kim, 2012) show sequential maps dominate children's representations, with increased complexity and environmental awareness associated with age and mobility. This study adopts cognitive mapping to explore how children perceive urban settings and whether digitalization is shifting developmental thresholds toward earlier ages.

METHOD

Before presenting the methods, the research design is outlined as a qualitative–quantitative mixed strategy, linking theoretical inquiry with an empirical case study to ensure consistency between data collection, analysis, and the study's overall aims.

Research Design and Methods

This research begins by establishing a theoretical background and then developing a hypothesis. Building on this foundation, preparations for cognitive mapping are conducted, with a selected case study as the basis for data collection. The data is then analyzed, and the results are evaluated to test the initial hypothesis. Each stage is carefully interconnected, facilitating a systematic examination of the theory from its conceptual groundwork to the analysis of findings; see Figure 2.

The overall research process is structured as illustrated below Figure 3.

Based on this methodological structure, the case study has identified significant correlations around the following questions:

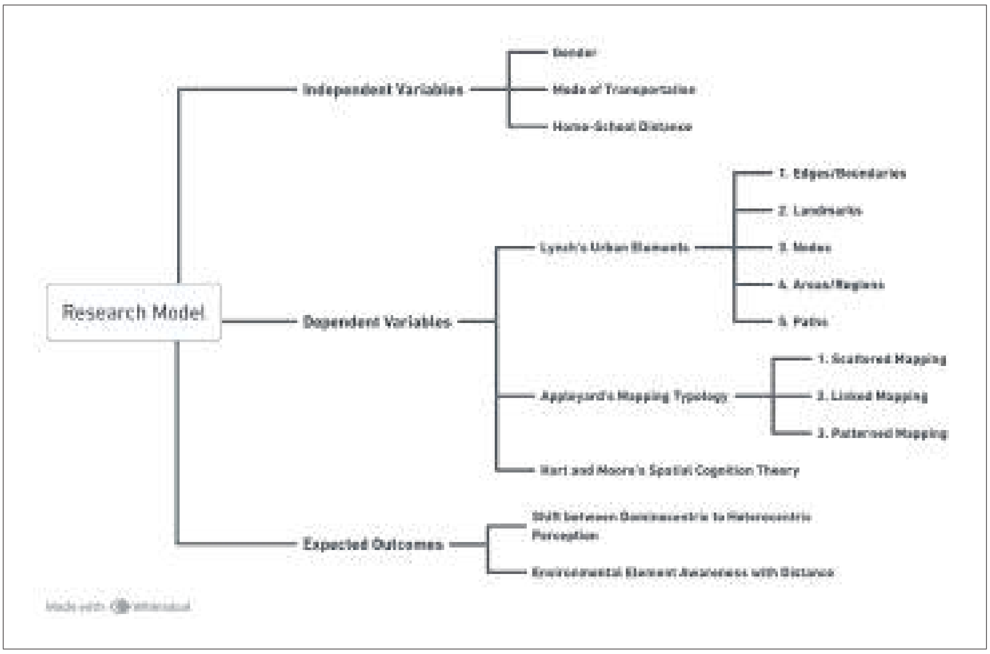

Figure 2. Methodological framework of the study.

- What are the cognitive and spatial boundaries of environmental and imaginative elements perceived by children at home or on their way to school and in their surroundings?
- According to Piaget (1954), what types of environmental image parameters do children present during the late pre-operational/early concrete period (6–7 years), and how do these relate to Hart and Moore's domicentric stage (3–8 years) with emergent heterocentric features?
- How does the domicentric stage (3–8, Hart and Moore) shape cognitive learning or understanding of spatial boundaries at ages 6–7 years, and which emergent heterocentric features appear?
- What are the effects of transportation types and itineraries between home and school on children's perceptions of environmental image parameters?

All drawings are coded and organized in three steps: (1) Each drawing is examined for the presence or absence of Lynch's five elements and Appleyard's mapping typologies. (2) Identified elements are categorized (e.g., type of boundary, type of landmark) and entered into structured coding sheets. (3) Scores and categorical values are transferred into a dataset for statistical analysis. This systematic procedure ensured consistency and comparability across all 52 participants.

Coding is performed by the first author. Inter-coder agreement reached 87%, which is considered satisfactory for qualitative-quantitative mixed coding.

All coding data are first compiled in a Microsoft Excel file. This file included both independent variables (e.g., gender, transportation type, parental education, screen time, distance) and dependent variables (e.g., Lynch's elements,

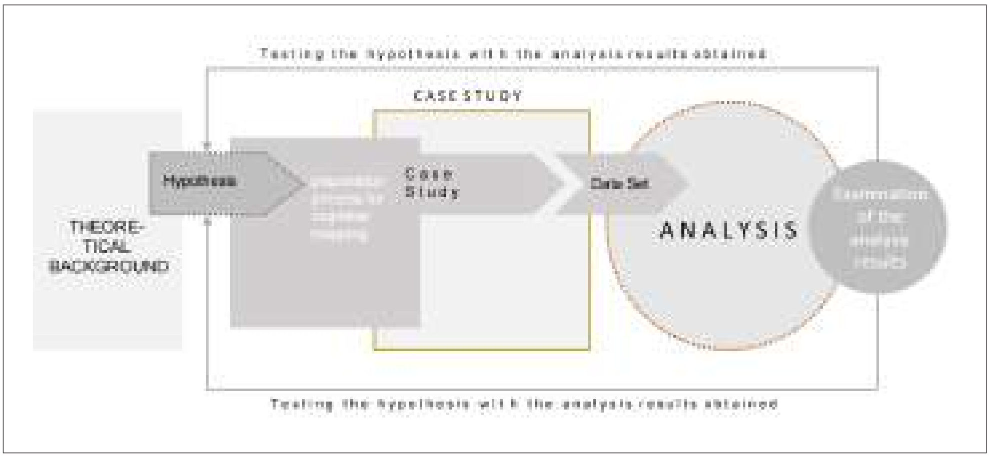

Figure 3. Research diagram.

Appleyard's typologies, Hart and Moore's thresholds). The finalized dataset was then exported into an SPSS file, forming the basis for statistical analyses.

Variables and Analysis

Expected frequencies met chi-square assumptions (>80% of cells >5); therefore, Pearson's chi-square was applied, and

Table 2. Independent and dependent variables for Pearson's chi-square analysis

Variable Type	Variable Name	Description
Independent Variables	Gender	Categorical variable representing the student's gender (girl/boy).
	Type of Transportation	Mode of transportation used between home and school (e.g., walking, private vehicle, school bus).
	Home–School Distance (km)	Measured distance (in kilometers) between the child's home and school.
	Parental Education Level	Educational attainment level of parents, categorized for analysis.
	Screen Time	Average daily screen exposure of the child, used as a cognitive engagement indicator.
Dependent Variables (Based on Lynch's Urban Image Elements)	Boundaries (Presence/Absence)	Indicates the presence of spatial boundaries such as ground lines, fences, roofs in children's drawings.
	Boundaries (Categorical)	Categorical classification of drawn boundary elements (e.g., enclosed gardens, property lines).
	Landmarks (Presence/Absence)	Identifies whether children represented distinctive landmarks such as home, school, sun.
	Landmarks (Categorical)	Types of landmarks drawn (e.g., natural, architectural, symbolic).
	Nodes (Presence/Absence)	Indicates the presence of spatial nodes such as intersections or gathering points.
	Nodes (Categorical)	Classification of node types (e.g., junctions, squares, courtyards).
	Paths/Lines (Presence/Absence)	Determines whether sequential or connecting paths are drawn between elements.
	Paths/Lines (Categorical)	Types of drawn paths (e.g., straight route, fragmented lines, circular paths).
	Regions/Districts (Presence/Absence)	Identifies spatial zoning or grouping, such as green areas, parking, building clusters.
	Regions/Districts (Categorical)	Categorization of districts based on function (e.g., residential, educational, recreational).
Theoretical Constructs	Mapping Typology (Appleyard)	Classification of children's drawings into mapping types Scattered / Linked / Patterned.
	Cognitive Development Threshold (Hart and Moore)	Developmental classification based on spatial complexity and organizational hierarchy in drawings Egocentric / Domicentric / Heterocentric / Euclidean.

Figure 4. Case study area (Google Earth, 2025).

Fisher's exact test was not required. Descriptive frequency/percentage tables were used to cross-check robustness (see Table 2).

This approach allowed for a detailed analysis of how spatial elements in children's drawings relate to cognitive mapping processes. The dependent variables in this study encompass a range of spatial and cognitive elements, assessed for their presence or absence and categorized based on mean scores. These include edges and landmarks (such as home or school representations), areas or districts, topological nodes (like rooms or domains), and paths or lines, all recorded in tally sheets. Additionally, the study evaluates the type of mapping used and a cognitive development threshold, both categorized similarly to assess developmental insights. This approach allows for a detailed analysis of how these spatial elements relate to cognitive mapping processes.

Case Study Description

In line with this methodological structure, the study focuses on a specific sample group—primary school children residing in the metropolitan city of Istanbul.The research aims to shed light on the environmental factors shaping children's perceptual world. It aims to examine how various environmental and imaginal influences impact the cognitive and perceptual development of 6-7-year-old children, particularly within the context of their daily experiences between home and school; see Figure 4.

The research was conducted at a primary school in Kadıköy, Istanbul with a sample of 52 first-grade students, including 22 girls and 30 boys.

Data Collection Procedure

Children were asked to draw their homes and schools in two stages: first using lead pencils and then blue pencils. This method enabled the analysis of memory processes in early and later stages. Drawings were completed under the supervision of the class teacher and the researcher over two days.

Parents provided sociodemographic data regarding gender, mode of transportation, screen time, home–school distance, and parental education. Distances were categorized into three groups: 0–4 km, 5–7 km, and 8–40 km.

Analysis Framework

Children's drawings are initially examined through Lynch's (1960) spatial elements (paths, edges, districts, nodes and landmarks) and Appleyard's (1970) typologies (scattered/linked/patterned). A standardized framework for scale mapping and typology is adopted to ensure consistency across interpretations. Micro-scale corresponds to egocentric and domicentric stages, meso-scale to heterocentric, and macro-scale to Euclidean. Non-framework terms (e.g., allocentric) are avoided, and Appleyard's triad is uniformly retained as scattered/linked/patterned.

This standardization ensured that the analysis remained theoretically grounded while guaranteeing comparability across the different spatial representations produced by the children.

Illustrative Case

To exemplify the process, Table 3 below presents the data coding for a 6-year-old girl (Participant 11) who drew her home-to-school route; see Figure 5.

Table 3 shows the variables and their values used in the coding process of Participant 11's drawing representing her journey from home to school.

Participant 11, A Girl's Route Mapping Interpretation

The drawing analysis in Figure 6 represents the spatial journey of a 6-year-old child (Participant No: 11) between home and school. The child illustrates the daily routine using key visual elements, notably placing a ground line as a boundary separating the home, school bus, and school buildings. Home and school are represented as landmarks, while the route connecting them forms a sequential pattern. The representation indicates a "linked type" mapping typology, reflecting a heterocentric spatial perception.

Landmarks Home and School

The child represents "home" and "school" as clear landmarks (Count: 2), indicating the early recognition of fixed reference points within their environment. A path connecting these landmarks reflects a linked-sequential mapping typology (Appleyard Typology), where spatial awareness emerges through direct experiential references rather than abstract reasoning. This aligns with Hart and Moore's heterocentric stage of spatial perception (1973). These stable points also signal developing spatial permanence, associated with late memory.

Path and Route

The presence of boundaries (fences and roads, Count: 2) reinforces the concept of spatial partitioning. However, understanding of nodes remains limited, with only one vaguely suggested by a crowd in front of the school. By linking home and school on the same plane, the child reflects Appleyard's "linked-sequential mapping" typology.

Edges (fence, road, home–school boundary) illustrate this ability to divide space—an indicator of late-memory abstraction.

Node: The group of people near the school functions as a nascent nodal point, showing emerging awareness of complex spatial functionality (late memory).

The drawing omits complex relational elements such as road networks and functional intersections, suggesting that relational spatial logic is still forming.

Natural features (Cloud, butterfly, bird, tree); these are simple environmental elements directly observed by the

Figure 5. Home-to-school drawing of participant 11.

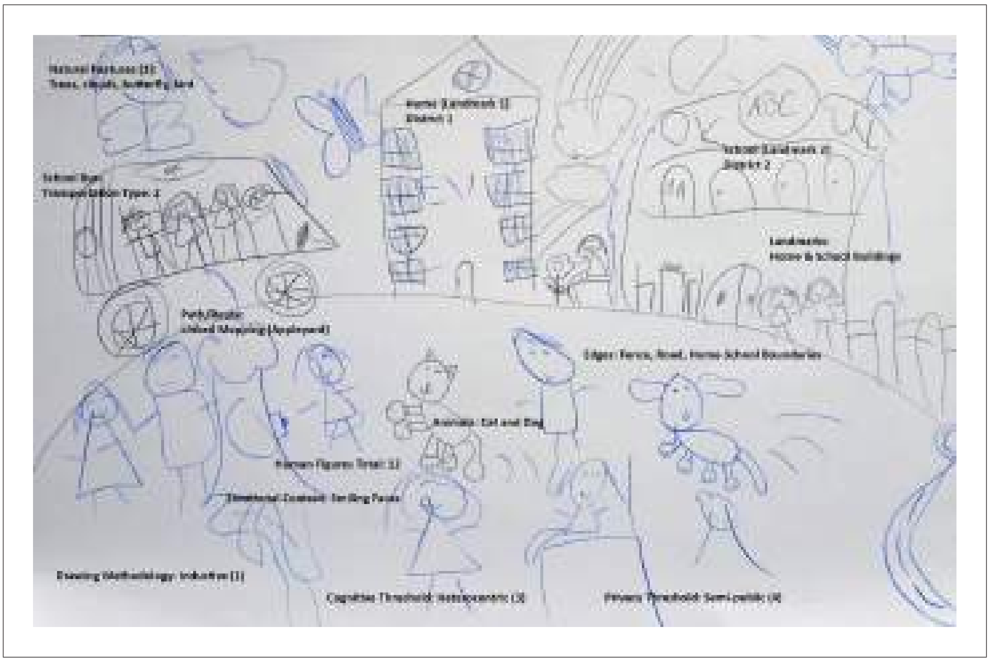

Figure 6. Interpretation of participant 11, a girl's route map.

child, reflecting early memory based on visibility. Animals (cat and dog); familiar and concrete figures from everyday life, belonging to early memory.

Human figures (Approx. 12 in total); friends, family, or groups of people are represented based on direct experience rather than abstraction, thus linked to early memory.

School bus (Transportation type: 2); a routine and directly observed feature of daily life, categorized as early memory.

Emotional content (Smiling faces); simple emotional markers derived from observation, indicating early memory.

Collectively, these details show emerging social awareness while remaining concrete and observational. The drawing methodology is inductive (child-centered, spontaneous structure). The privacy threshold is categorized as semi-public (Category: 3), implying an intermediate sense of accessibility and openness. Overall, the drawing illus-

Table 3. Data coding for Participant 11's home-to-school route

Variable	Value
Participant No	11
Gender	1[1]
Type of Transportation	2[2]
Daily Screen Time (Hours)	2[3]
Screen Time Category	2[3]
Out-of-Home Activity Frequency	2[4]
Out-of-Home Activity Category	2[4]
Home–School Distance (km)	1[5]
Home–School Distance Category	1[5]
Home–School Travel Time (min)	12
Home–School Travel Time Category	2[6]
Neighborhood Type	2[7]
Parental Education Level	3[8]
Lynch's Elements – Edges	Present[10]; Total Category: 2[9]
Lynch's Elements – Landmarks	Present[10]; Total Count: 2; Category: 2[9]
Lynch's Elements – Districts	Present[10]; Total Count: 2; Category: 2[9]
Lynch's Elements – Nodes	Present[10]; Total Count: 1
Lynch's Elements – Paths/Lines	Present[10]; Total Count: 2; Category: 2[9]
Spatial Representation Typology (Appleyard)	2[11]
Virtual World Integration	2[12]
Nature Attributes	Present[10]; Total Count: 8; Category: 3[13]
Emotional Attributes	Present[10]; Total Count: 4; Category: 3[13]
Human Attributes	Present[10]; Total Count: 12; Category: 3[13]
Drawing Methodology	1[14]
Cognitive Development Threshold (Hart and Moore)	3[15]
Privacy Threshold	3[16]

a. Gender: 1=Girl; 2=Boy; b. Type of Transportation: 1=Walking; 2=Vehicle Travel; c. Screen Time: 1=0–2 hours; 2=3–4 hours; 3=5–6 hours; d. Out-of-Home Activity Frequency: 1=0–2 hours; 2=3–4 hours; 3=5–6 hours; e. Home–School Distance: 1=0–4 km; 2=5–7 km; 3=8–40 km; f. Home–School Travel Time: 1=0–12 min; 2=13–24 min; 3=25–50 min; g. Neighborhood Type: 1=Urban Center; 2=Planned Urban Area; 3=Suburban Area; h. Parental Education: 1=Primary; 2=Secondary; 3=Undergraduate; 4=Postgraduate; i. Lynch's Elements Categories: 1=Basic; 2=Moderate; 3=Complex; j. Presence/Absence: 0=Absent; 1=Present; k. Appleyard Typologies: 1=Scattered; 2=Linked; 3=Patterned; l. Virtual World Integration: 1=Absent; 2=Present; m. Attributes (Nature, Emotional, Human): 1=Low; 2=Medium; 3=High; n. Drawing Methodology: 1=Inductive; 2=Deductive; o. Cognitive Development Thresholds (Hart and Moore): 1=Egocentric; 2=Domicentric; 3=Heterocentric; 4=Euclidean; p. Privacy Thresholds: 1=Private; 2=Semi-private; 3=Semi-public; 4=Public.

trates an observational and fragmented spatial representation, where immediate experience shapes the environmental image.

Early-memory elements dominate (nature, animals, vehicles, people), while late-memory elements appear in the home–school link, path, boundaries, and node, indicating emerging relational abstraction. These findings support the gradual progression of spatial understanding through cognitive growth and environmental interaction.

Participant 36, A Boy's Route Mapping Interpretation

The drawing in Figure 7 represents the spatial perception of a child who depicts his environment through a catalog-like arrangement of distinct elements. The composition follows

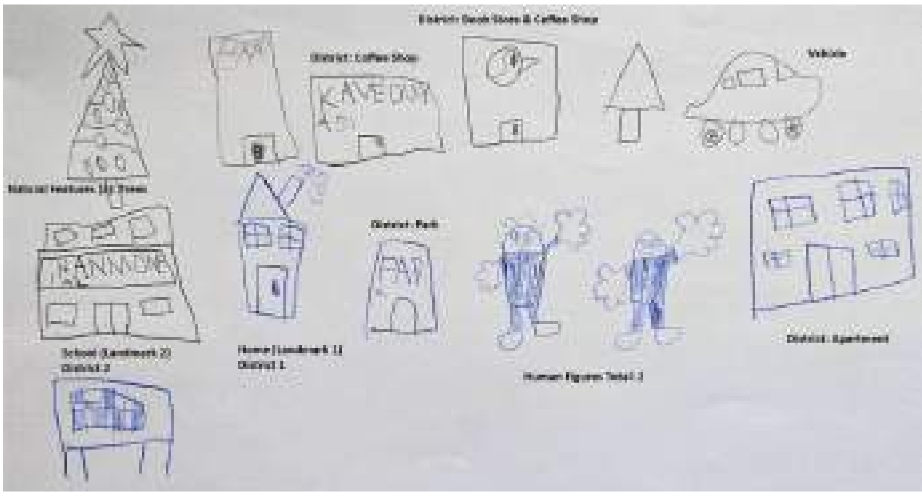

Figure 7. Interpretation of participant 36, a boy's route map.

a scattered mapping typology (Appleyard 1970), with multiple landmarks placed independently, without continuous routes or a connecting ground line. This scattered structure indicates an early stage of heterocentric perception, where places are cognitively recognized and named but not yet integrated into a relational system.

The child includes a series of symbolic buildings, a "park" gate, a car, trees, and two human figures. The use of labels and names on buildings emphasize recognition and memory coding rather than sequential representation. The absence of a defined path suggests that relational spatial abstraction is still developing.

Landmarks and Emotional Markers

The drawing features multiple landmarks—at least five distinct buildings, some labeled with words, and a "PARK" entrance. The symbolic use of writing demonstrates the child's effort to identify and codify specific places, reflecting permanence and advanced spatial awareness. Such labeling processes are associated with late memory.

Path and Route

No connecting path or ground line is depicted between the landmarks. The scattered typology highlights the absence of sequential mapping and emphasizes the listing of places rather than their interconnectedness. This indicates that relational spatial logic remains limited.

Edges and Nodes

The drawing omits explicit dividing elements such as roads, fences, or boundaries, showing that the concept of spatial partitioning is not yet present. The "PARK" entrance functions as a symbolic node, serving as an access or gathering point. In the absence of routes, this node remains isolated, reflecting an emerging awareness of nodal function.

Early Memory Elements

Natural features (trees, decorated tree): simple environmental symbols directly observed, categorized as early memory.

Human figures (2): large, central figures reflect social awareness but are not integrated into a wider spatial context (early memory).

Vehicle (car): drawn as an isolated object without a road network (early memory).

Late Memory Elements

Labeled buildings: writing on facades shows symbolic coding and permanence (late memory).

Park entrance: functions as a symbolic gateway and node (late memory).

Building facades (doors/windows): the regularized architectural representation suggests structural abstraction beyond simple observation (late memory).

The drawing methodology is additive and enumerative, with elements placed individually rather than relationally integrated. The privacy threshold corresponds primarily to public/semi-public domains (shops, institutions, parks), with no representation of private domestic interiors.

In this drawing, early-memory elements dominate in natural and social features, while late-memory elements appear in labeled buildings, the park gate, and structured facades, reflecting growing symbolic abstraction.

Overall, the child demonstrates the ability to recognize, name, and codify multiple landmarks but has not yet established systematic spatial connections between them. This scattered typology and symbolic labeling together suggest a transitional heterocentric stage, where places are recognized but relational logic is only beginning to form.

Comparison of Spatial, Social, and Emotional Elements in Two Mapping Styles

Table 4 below comparatively demonstrates how the drawings of two students evolved into different cognitive mapping typologies in terms of spatial, social, and emotional components. Specifically, the female student's drawing exhibits a relational and connected structure, while the male student's drawing is more object-oriented and based on a scattered typology.

Participant 11 (girl) demonstrates a more integrated depiction of routes, landmarks, and boundaries, indicating an early heterocentric tendency in which relational spatial abstraction begins to emerge. Participant 36 (boy) primarily emphasizes naming and cataloging landmarks without showing relational connections, reflecting a symbolic, label-based memory stage. These individual patterns represent variations within the sample rather than gender-specific tendencies.

RESULTS

Pearson's chi-square tests are applied to all cross-tabulated variables using IBM SPSS Statistics 28.0. The frequency distributions within contingency tables are checked to verify adequate cell counts, and statistical significance is set at $p<0.05$. As the minimum frequency requirements are satisfied across categories, no Fisher's Exact tests are performed. These procedures ensure the robustness of the reported correlations. The analyses reveal the relationships between children's drawings and the independent variables (gender, mobility, home–school distance, and parental education), as presented in Figure 8, highlighting how these factors affect children's spatial perceptions and cognitive development.

In the analysis of children's drawings cognitive maps, the distribution of cognitive image analyses under the home-school route analysis can be explained in Figure 8 as follows:

Boundaries-Edges: The distribution shows that 98% of the examined students included boundaries in their early memory drawings, while 2% did not. These ratios indicate that students commonly reflect the concept of boundaries in their cognitive maps. According to early memory in the students' drawings, boundaries such as ground lines, sky

Table 4. Comparative Table of Cognitive Mapping Features

Category	Participant 11 (Linked Mapping), A Girl Student	Participant 36 (Scattered Mapping), A Boy Student
Landmarks (Late)	Home and School clearly depicted as fixed reference points (2 landmarks).	Multiple labeled buildings, "PARK" entrance; naming/writing shows symbolic coding.
Path/Route (Late)	Linked-sequential mapping (Appleyard Type 2); path connects home–school.	No connecting route; scattered typology, places listed individually.
Edges (Late)	Fences, road, home–school boundaries represented; spatial partitioning visible.	No edges or boundary elements; spatial partitioning absent.
Nodes (Late)	Crowd in front of school acts as an emerging node.	"Park" entrance functions as symbolic node, but isolated.
Natural Features (Early)	Clouds, butterfly, bird, tree (Count: 8).	Simple tree and decorative "Christmas tree."
Animals (Early)	Cat and dog included.	No animals.
Human Figures (Early)	~12 people; smiling faces, social awareness.	2 large figures; central placement but limited social context.
Transportation (Early)	School bus (Transportation type: 2); daily routine symbol.	Car without road; isolated object.
Emotional Content (Early)	Smiling faces → positive affect, emerging social awareness.	Absent (no clear emotional indicators).
Privacy Threshold	Semi-public (Category 3).	Public/semi-public; institutional/park spaces dominate.
Mapping Typology	Linked, relational connections emerging.	Scattered typology, catalog/enumerative layout.
Cognitive Development Thresholds	Heterocentric	Heterocentric
Drawing Methodology	Inductive	Inductive
Memory Balance	Mix of early + late	Early dominates (objects, people), with pockets of late memory (labels, symbolic coding).

boundary lines, garden fences, building roofs, and building frames are more frequently included.

Landmarks: The home environment is accepted as the first landmark and the school environment as the second landmark in the children's drawings. The distribution shows that 86% of the examined students included these landmarks in their primary early memory drawings, while 14% did not. These ratios indicate that students reflect the concept of landmarks in their cognitive maps.

Areas-Districts: The urban areas located between home and school, including home gardens, school yards, shopping areas, and parks, are examined in the drawings. This-distribution indicates that 90% of the examined students' memory drawings were present for districts, while 10% were absent. These ratios show that the students have the concept of districts and areas in their maps.

Nodes: Nodes are the intersections of roads and streets near home and school. The distribution indicates that 92% of the examined students did not include nodes in their drawings, while 8% did. These results show that nodes are predominantly absent in the students' drawings. Nodes and junctions are elements expected in children's drawings as extensions of heterocentric space and Euclidean space (see Ünlü & Çakır 2002).

Paths-Lines: Roads, streets, and connecting elements between home and school were examined. The distribution indicates that 68% of the examined students did not include roads/lines in their drawings, while 32% did. This shows that lines (roads) are less frequently observed in the students' drawings. This outcome may be expected as it indicates that higher age groups typically deal with projective and Euclidean spatial solutions.

Mapping Typologies: The drawing typologies vary according to children's spatial responses. Based on Appleyard's (1970) spatially dominant maps, the scattered typology includes drawings with unconnected, free-floating objects. The linked typology features paths or connecting lines between the home and other elements, while the patterned typology shows organized groupings of connected elements forming district-like areas.

According to this typological analysis, on an urban scale, based on the mapping data analysis, 54% of the children's drawings fall under scattered mapping, 16% under linked mapping, and 30% under patterned mapping. This result shows that spatial perception is relatively higher at this age threshold, and the presence of patterned typology as a secondary level demonstrates that children transition from scattered to patterned drawings at this age. The fact that children from this age group use spatial mapping typologies, as defined by Appleyard (1970), more than sequential typologies suggests that they need more time to place experiences and information sequentially and consecutively. This aligns with Piaget's (1954) theory, which shows that

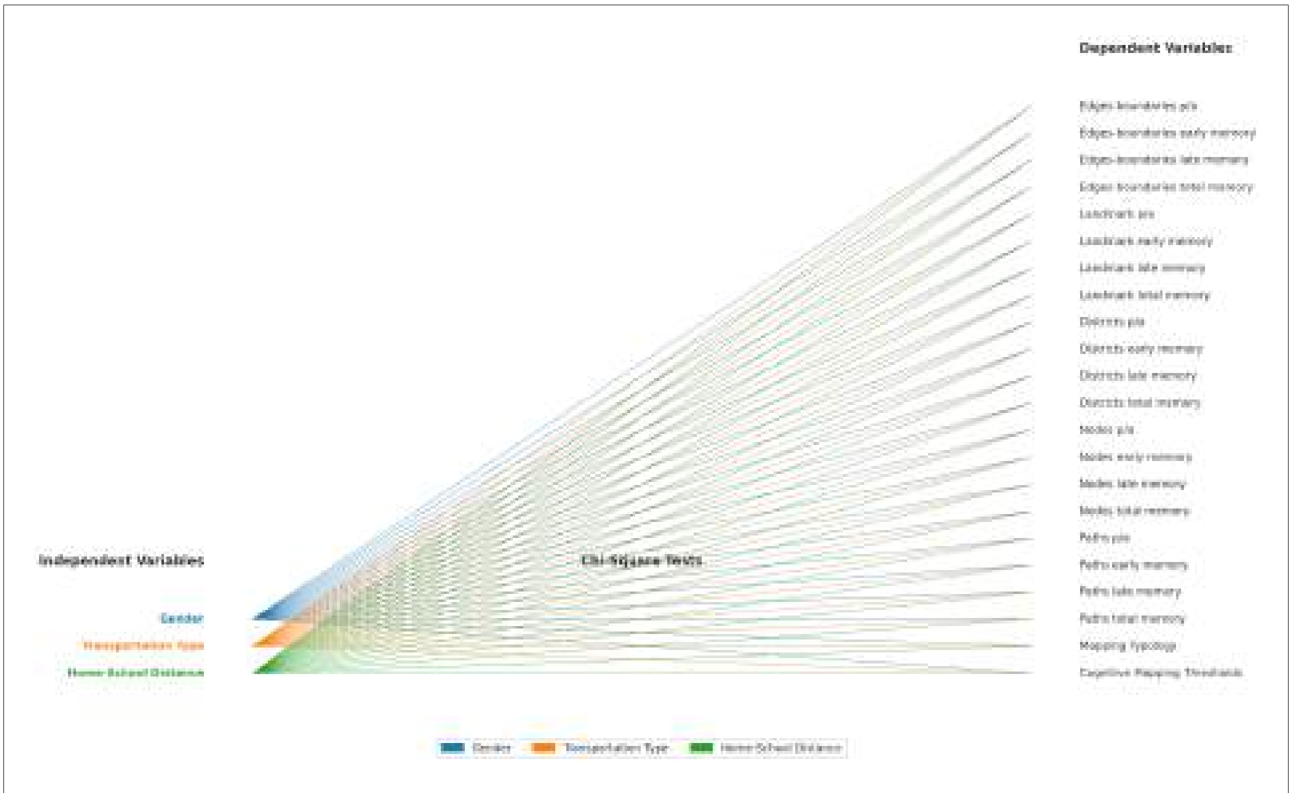

Figure 8. Correlation overview.

the children in the pre-operational stage still need to be ready for sequential and consecutive drawings related to the concrete operational stage.

Cognitive Thresholds: This analysis is based on Hart and Moore's (1973) approach and their definitions of children's spatial cognition theory development. According to the distribution, 64% of the examined children are at the heterocentric cognitive development stage threshold, indicating a solid perception of their homes and surroundings (meso environment). Because heterocentric is theorized as 8–12, these findings are interpreted as early/emergent features at ages 6–7. The next threshold is the domicentric stage, related to perception within the home (micro-environment), which accounts for 18%-an expected result. However, the egocentric threshold (personal space) follows at 16%, which is surprising. According to Piaget (1954), this stage corresponds to the 0–3 age group, so it is concerning that 16% of children still exhibit traits of this infantile stage in their cognitive perception; these are considered residual features rather than age-appropriate dominance. Only 2% of the children are at the Euclidean threshold, indicating perception at the urban (macro) scale. Taken together, these thresholds reveal a developmental progression across the manuscript using the scale labels: micro (egocentric/domicentric), meso (heterocentric), and macro (Euclidean).

These results align with Piaget's (1954) theory and Hart and Moore's (1973) framework of children's spatial cognition, indicating a developmental shift from natural to rational perception and individual to collective awareness. The findings highlight the significance of the child's position within both home and community settings. Within the scope of this study, the transition from domicentric space at ages 3–8 to heterocentric space at ages 8–12 can be interpreted as a shift from "natural" to "rational" will and from "community" to "society." This progression reflects a movement from individuality and egocentrism toward an emerging sense of public consciousness. The study underlines the importance of the child's role within domestic and communal environments in contemporary urban contexts.

Correlations

In the second part of the field study, the significant correlations obtained in the urban-centered-school-centered part are shown in Figure 9. Six significant results at the 0.05 probability level were obtained out of sixty-six correlations.

Figure 9 above summarizes the significant correlations between independent and dependent variables, while Table 5 presents the detailed Pearson's chi-square test results, highlighting the statistically significant relationships between various variables and the spatial elements depicted in children's drawings.

As detailed in Table 5, all significant results met the statistical validation criteria (χ^2 values reported with degrees of freedom and p-values<0.05). These findings' robustness is verified by cross-checking frequency distributions, ensuring that the statistical significance reflects consistent patterns in the underlying data. *However, given the small sample size (n=52), these Pearson's chi-square test results should be*

Table 5. Correlations and Pearson's Chi-Square Results

Variable	Statistical Test & Value (Pearson Chi-Square)	p-Value <0.05	df	Key Findings
Gender-Paths	χ^2= 4.695	0.030	1	Girls drew more lines/paths than boys in the area between home and school, showing a statistically significant relationship.
Gender-Mapping Typology	χ^2= 12.836	0.002	1	Boys predominantly use scattered mapping; girls favor linked typologies, showing significant correlation between gender and typology.
Transportation/Mobility Type-Landmarks	χ^2=4.578	0.032	1	Children using vehicles highlight landmarks more prominently in drawings compared to those walking.
Home-School Distance - Recognition of Nodes	χ^2= 4.554	0.033	1	Longer home-school distances correlate with more nodes in drawings, suggesting increased node perception with travel duration.
Home-School Distance - Edges/Boundaries	χ^2= 12.474	0.050	6	Students closer to school include more boundaries (e.g., fences, roofs), indicating proximity influences spatial perception.
Home-School Distance - Cognitive Development Stages-Thresholds	χ^2=13.658	0.034	6	Proximity to school impacts cognitive thresholds: shorter distances show detailed perceptions, longer distances indicate broader spatial awareness.

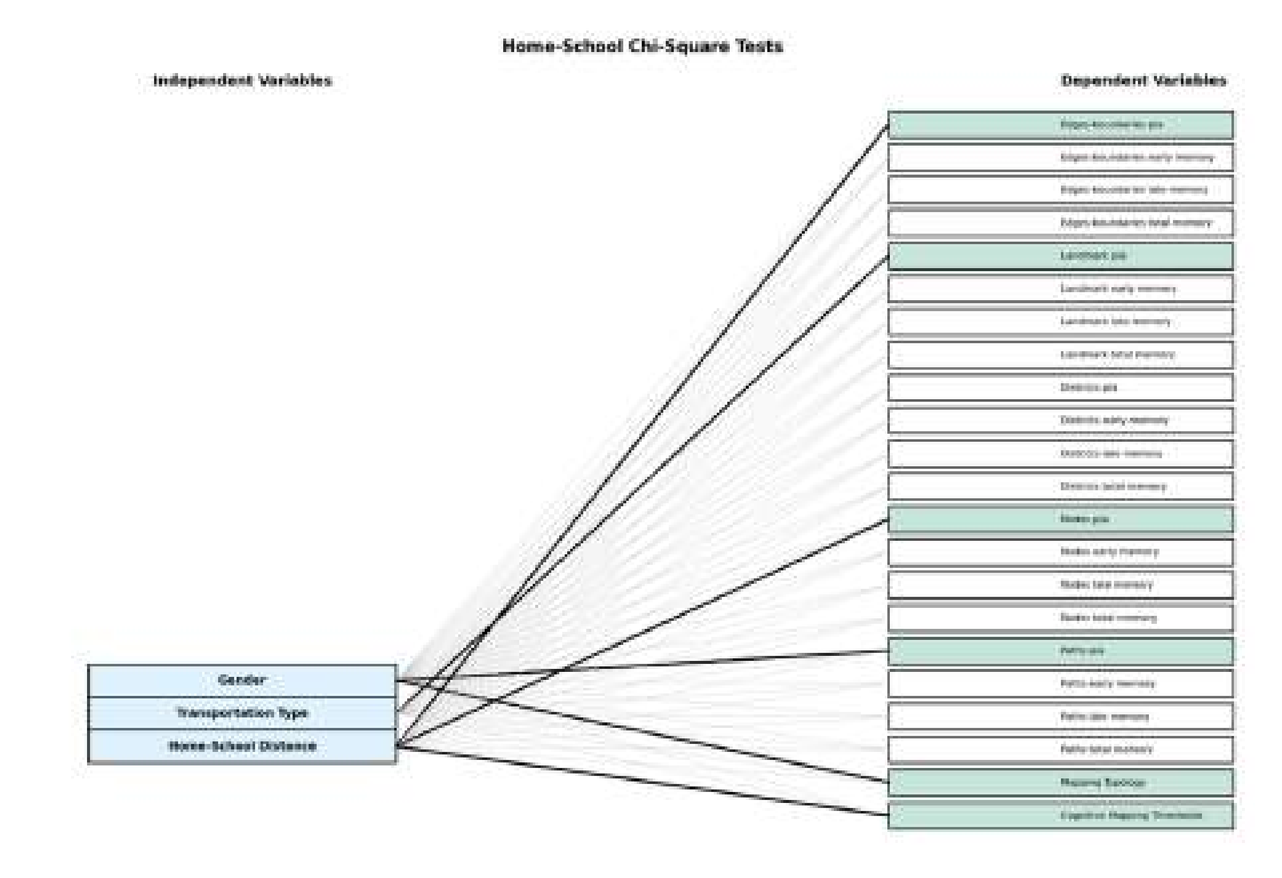

Figure 9. Significant Pearson's chi-square correlations between home, school, and urban areas.

interpreted cautiously. The statistical relationships observed are indicative rather than conclusive, providing exploratory insights into potential trends within the studied group.

Gender-Paths: The Pearson chi-square test (χ^2=4.695, df=1, p=0.030<0.05) indicates a statistically significant but moderate association between gender and including lines/paths. Within this sample, a higher proportion of girls' drawings included paths than boys', suggesting a slight variation in the depiction of movement routes. However, this result should be interpreted cautiously, given the small sample size and the differing findings reported by Ünlü & Çakır (2002), who observed an opposite tendency. Given the sample size and context-specific literature reporting mixed patterns, this association should not be generalized beyond this cohort.

Gender-Mapping Typology: The Pearson chi-square test (χ^2=12.836, df=1, p=0.002<0.05) reveals a significant association between gender and mapping typology. In this dataset, scattered mapping appeared more frequently in boys' drawings, whereas linked mapping was more common among girls. These tendencies are statistically significant within this case study; however, given the sample size and context-specific literature reporting mixed patterns, this association should not be generalized beyond this cohort.

Transportation/Mobility Type-Landmarks: The test indicating the transportation type used by children during the home and school itinerary and the existence of landmarks in their drawings presented a significant correlation χ2=4.578, df=1, p=0.032<0.05. The Pearson chi-square test result indicates a significant relationship between the transportation children use to travel to school and the existence of landmarks in drawings. According to this result, children who come to school by vehicle include landmarks more prominently in their drawings, as shown in the total memory analysis.

Home-School Distance-Recognition of Nodes: Nodes' recall has a statistically significant relationship with the distance between home and school. χ^2=4.554, df=1, p=0.033<0.05. The analysis of the relationship between home-school distance and the presence of nodes in children who draw the area between home and school shows a p-value of 0.033, indicating significance. Nodes are rarely seen in the drawings of students with a short home-school distance. However, in children with a longer home-school distance, the presence of nodes increases, and their distribution spans a wider range. This can be interpreted as follows: children perceive more nodes as the travel duration between home and school increases.

Home-School Distance-Edges/Boundaries: This correlation indicates a significant relationship between the distance from home to school and how children perceive and draw boundaries. The distance they travel daily may influence their understanding and representation of spatial boundaries. Students living closer to school include more boundaries and edges in their drawings, suggesting proximity influences spatial perception.

The categorical distribution according to observed frequencies as the mean scores of the distance from home to school for students drawing their home environment and surroundings are as follows: 0-4 km is the first categorical value, 5-7 km is the second categorical value, and 8-40 km is the third categorical value. The relationship between home-school distance and the boundaries category is found to have a Pearson chi-square value of x^2=12.474 with p=0.050", df=6 indicating a marginal association (p=0.050). According to this data, students who live closer to the school tend to include more boundaries in their drawings, such as ground lines, sky boundary lines, garden fences, building roofs, and building frames. This finding suggests that the proximity of students' homes to their schools influences how they perceive and depict boundaries in their drawings. Understanding this relationship provides insights into how everyday experiences, such as commuting distances, impact children's spatial cognition and representation.

Home-School Distance-Cognitive Development Stages-Thresholds: This correlation highlights a significant relationship between the distance from home to school and the cognitive development thresholds, such as egocentric, domicentric, heterocentric, and Euclidean spatial perceptions. The distance they travel may influence their cognitive development regarding spatial awareness and understanding. Children living closer to school show more detailed spatial perceptions, while those farther away develop broader spatial awareness. The categorical distribution (according to mean scores) of the distance from home to school for students drawing their home environment and surroundings is as follows:

0-4 km is the first categorical value, 5-7 km is the second categorical value, and 8-40 km is the third categorical value. The case study examines how this distance influences various cognitive development thresholds: egocentric, domicentric, heterocentric, and Euclidean spatial perceptions.

The relationship between home-school distance and cognitive development thresholds is significant, with a Pearson chi-square value of χ^2=13.658 and p=0.034<0.05, df=6. The analysis suggests that children living closer to school (0-4 km) exhibit heterocentric and domicentric perceptions, indicating a more detailed understanding of their immediate home and surrounding environment (semi-public, fragmented). In contrast, children living farther from school (8-40 km) may develop a broader spatial perception, potentially due to their exposure to a more comprehensive range of environments during their home-school route. The distance from home to school children's cognitive development is related to spatial awareness and understanding. Those with shorter commutes may have a more focused perception of their immediate environment, while those with longer commutes might develop a broader understanding of space. This finding suggests that the distance between home and school significantly shapes children's cognitive development and spatial perception. Understanding these relationships can provide insights into how daily experiences and environmental exposure influence children's cognitive and spatial development.

This study examines children's cognitive mapping abilities and spatial perception, focusing on urban analysis. The summary findings of this study, which investigates the elements children use to understand and represent their environment, are as follows:

Cognitive Image Analysis: Children's cognitive maps were analyzed using five essential elements: boundaries/edges, landmarks, areas/districts, nodes, and paths/lines. Children frequently represented edges and landmarks in their drawings; more than 90% of students included these elements. This shows that boundaries (edges) and landmarks are critical to how children perceive and map their home-school route environment.

Mapping-Drawing Typology: Children's drawings are classified using three mapping typologies: scattered, linked, and patterned. The scattered mapping type is the most common; more than 50% of students use this typology in city-related analyses. The patterned mapping type is the second most used type by about 30% of students; the linked mapping type is the least common, with about 16%. This shows that, regardless of the context, children tend to perceive spaces in a fragmented or non-linear way rather than connecting roads or paths.

Cognitive Development Thresholds: The analysis shows that most children (about 64%) are at the heterocentric threshold, demonstrating their ability to relate to broader environments such as home and surroundings (meso-environment). A smaller proportion display predominantly egocentric perceptions (micro-environment), while only 2% reach the Euclidean threshold, reflecting an urban-level understanding (macro-environment).

The Effect of Distance Between Home and School: Children living closer to school included more roads/lines in their drawings, suggesting that proximity directly influences their spatial perception.

Gender Differences: The analysis related to the home indicates a statistically significant correlation between gender and the depiction of districts. In the home-centered drawings, girls more frequently included a variety of interior and exterior areas.In the city-centered drawings, male participants more often represented elements such as playgrounds, nearby cafés, and ice cream shops.

While these differences are not uniformly pronounced across all cases, they suggest that individual factors, including gender, may influence certain spatial representation tendencies.

In summary, the two-stage case study reveals several overarching findings regarding children's cognitive mapping abilities, spatial perception typologies, and the effect of proximity on their spatial understanding. These findings emphasize the significance of boundaries, landmarks, and familiar spaces in children's cognitive development within the urban context. In addition, they emphasize that children's spatial perception is primarily heterocentric.

According to this study, although distance from school and mobility are essential factors in how children perceive the city, the recognition of heterocentric space by a high percentage of children aged 6-7 years may reflect early exposure to public and shared environments. In this sense, changes in cognitive development thresholds and early perception of heterocentric public spaces are detected in this case study. However,approximately 16% of first-grade participants still displayed egocentric tendencies in spatial perception related to educational and pedagogical contexts.

DISCUSSION

This study identifies gender-related variations in children's spatial representations. Some girls produced more detailed and connected drawings, whereas some boys tended to depict more fragmented or scattered forms. These differences are context-dependent rather than inherent, reflecting variations in environmental exposure, mobility opportunities, and task framing. Boys in this sample often incorporated urban-scale elements such as playgrounds, cafés, and shops, suggesting a broader yet more fragmented perception of space. Overall, the findings align with previous studies (Ünlü & Çakır, 2002; Rzhanova et al., 2020; Lynch, 1960), emphasizing that children's spatial representations are shaped by environmental interaction rather than gender itself.

Moreover, Matthews (1983) found that young children's ability to understand and represent large-scale environments varies with age, highlighting the developmental nature of spatial cognition. Children's capacity to mentally organize and represent complex environmental spaces increases as they grow. This aligns with Hart and Moore's (1973) spatial cognition framework, which indicates that children aged 6-7 years develop heterocentric spatial awareness and demonstrate early sensitivity to public spaces. This progression partially corresponds with Piaget's (1954) stages of cognitive development, particularly the concrete operational stage (ages 7-11). The earlier emergence of heterocentric spatial awareness in this sample is discussed as early/emergent rather than full stage attainment and can be analyzed through environmental parameters and digital mediation.

This early emergence, also noted in the literature, some 6–7-year-old children in our sample displayed early signs of heterocentric perception. These can be interpreted as emergent rather than fully developed features. Similar tendencies have been noted in the literature: Ünlü & Çakır (2002) emphasized gender-based differences in spatial focus, Rzhanova et al. (2020) observed developmental variability in spatial and cognitive tasks, and Coşkun & Kaymaz (2022) found that urban environmental complexity influences spatial awareness in older children (7–11 years). While our case study suggests that heterocentric indicators may appear earlier than Hart and Moore's (1973) framework predicts, such interpretations remain context-specific and should be treated cautiously.

These findings, which challenge traditional developmental timelines, suggest that children transition from home to urban spaces earlier, with virtual environments playing a pivotal role. Although virtual environments offer fragmented and distorted spatial experiences compared to physical interactions, they allow children to view environmental parameters from broader perspectives in their memory and representations. Furthermore, digital media is suggested to enhance visual-spatial skills, such as recognizing patterns and understanding spatial relationships, potentially altering perceptions of environmental boundaries. Integrating digital media with real-world activities offers new perspectives that enrich spatial concepts and cognitive development.

The impact of environmental exploration on children's cognitive maps is shaped by factors such as distance and freedom of movement. Walking and longer routes support node recognition and broader spatial awareness, while shorter commutes emphasize boundaries and local edges. Children who walk and observe their surroundings improve the accuracy of their spatial models, while their mobility enhances their ability to acquire environmental knowledge effectively. This leads to better performance in mapping tasks and improves their spatial awareness. The distance between home and school significantly influences children's cognitive representations; children living closer to school tend to depict more boundaries and edges (e.g., fences and rooflines), while those living farther away develop broader spatial awareness, emphasizing nodes and landmarks. These findings align with Herman's (1980) study on the impact of environmental exploration on spatial cognition, highlighting that active interaction with the city enhances children's spatial awareness.

This study is consistent with the mobility-focused research of Damayanti and Kossak (2016), showing that children covering longer distances perceive their environments with a broader perspective. However, it contrasts with Park and Mi-Hui's (2012) findings that children's perception distance is limited to 100-500 meters. It was also found that the type of transportation children use correlates significantly with the presence of landmarks in their drawings. Children who commute by car emphasize landmarks more than those who walk. This supports Risotto and Tonucci's (2002) findings that freedom of movement impacts environmental learning. The results also contribute to Appleyard's (1970) sequential mental maps theory, explaining how vehicle-based journeys shape spatial perception.

The study further reveals that socioeconomic status and cultural context influence spatial cognition. Öztürk's (2009, 2015) studies indicate that children from lower socioeconomic backgrounds experience perceptual challenges, and Gillespie (2014) highlights the role of cultural context in shaping neighborhood perceptions. These findings are consistent with this study, which integrates individual variables to provide a holistic perspective on gender, mobility, and distance. For instance, children from higher socioeconomic backgrounds appeared to have broader environmental exposure, which may contribute to more structured mapping typologies. The findings align with Piaget's (1954) principles of assimilation and accommodation in adapting to the environment but suggest that modern environmental factors may alter traditional developmental processes, leading to earlier heterocentric spatial awareness. Lynch's (1960) theory on spatial elements such as paths, edges, and landmarks confirms their central role in children's cognitive maps and spatial perception.

This study contributes to understanding how gender, mobility, and spatial familiarity shape children's cognitive representations of their everyday environments. While the findings provide meaningful insights into these relationships, the relatively small sample size limits the statistical generalizability of the results. Given the small sample (n=52), single-school context, and categorical sparsity that can affect chi-square test stability and power, the findings should be considered exploratory. While expected-cell assumptions were checked, restricted generalizability remains a key limitation. Coding achieved satisfactory agreement (87%), yet single-site sampling and potential unmeasured confounds such as neighborhood form, parental trip patterns, and digital exposure granularity may have influenced outcomes. Future research should employ larger, multi-site samples, pre-registered analysis plans, and models that can accommodate covariates (e.g., logistic or multinomial regression) to test whether observed tendencies persist after adjustment. Longitudinal designs and mixed-methods triangulation (drawings, interviews, GPS/route audits) would help differentiate developmental change from context effects.

CONCLUSION

This study reveals the interaction between children's spatial cognition and variables such as gender, mobility, and cognitive thresholds. The findings suggest that contemporary environmental and social conditions enhance children's spatial awareness and support cognitive growth. Grounded in the theoretical frameworks of Piaget (1954), Lynch (1960), and Hart & Moore (1973), the research emphasizes the relationship between children's cognitive mapping abilities and their everyday environments.

To create child-friendly cities, educational and urban design strategies should be developed in an integrated manner. Policies encouraging outdoor activities and environmental exploration can strengthen children's spatial awareness, while urban planning should prioritize safe pedestrian networks, legible layouts, and sensory-accessible public spaces. Incorporating insights from children's cognitive mapping into design processes will help planners create more comprehensible and engaging environments for all young users, acknowledging gender-related spatial preferences in the process.

At the policy level, although this study did not directly measure policy outcomes, the findings-together with insights from previous literature-suggest that encouraging alternative modes of transportation, such as walking and cycling, may strengthen children's independent mobility and spatial familiarity by increasing their interaction with their surroundings. Similarly, the proximity between home and school, while not quantitatively assessed in this research, emerges as an important consideration for supporting children's daily spatial routines; this highlights the potential value of planning at the neighborhood level and improving the accessibility of local schools.

From an architectural perspective, the implications drawn from the findings point to the potential benefits of creating flexible modular spaces on the ground floors of residential buildings, which may serve as transition spaces for play, learning, and community interaction. These spaces should include interactive and sensory-rich elements suitable for the child's scale to enhance children's engagement with the built environment and support sensory learning opportunities.

Furthermore, the spatial elements identified in children's drawings may offer useful guidance for design considerations. The relatively limited depiction of roads suggests the importance of providing continuous and safe pedestrian routes around schools. The frequent inclusion of landmarks underlines the benefit of incorporating visible, child-scaled reference points-such as playgrounds, colorful façades, or distinctive trees-that can support wayfinding and strengthen the legibility of children's spatial environments.The scarce representation of nodal points indicates that intersections and gathering areas near schools could be designed with greater clarity and safety, serving as recognizable anchor points for children. These insights demonstrate how cognitive mapping findings can inform practical design solutions that improve child mobility, orientation, and comfort in urban areas.

As a result, designing urban areas based on childhood experiences requires an interdisciplinary approach that includes architecture, urbanism, education, and environmental psychology. Recognizing children as independent individuals and urban actors and including them in participatory design processes may contribute to constructing inclusive, resilient, and sustainable cities. In this context, child-friendly urban design that enhances legibility, safety, and sensory richness can foster cognitive development and create more livable, equitable, and future-oriented urban environments.

Given the study's exploratory scope and limited sample, the reported associations should be considered hypothesis-generating rather than confirmatory. Design implications are practice-informed suggestions that warrant testing in larger and more diverse settings.

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REFERENCES

Altman, I. (1975). *The environment and social behavior: Privacy, personal space, territory, crowding*. Brooks/Cole Publishing Company.

Appleyard, D. (1970). Styles and methods of structuring a city. *Environment and Behavior, 2*(1), 100–117. https://doi.org/10.1177/001391657000200106

Baksi, E. (2018). *Examination of children's space perception through their living environment* [Master's thesis]. Selçuk University.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*. Harvard University Press. https://doi.org/10.4159/9780674028845

Burkut, E. B., & Köseoğlu, E. (2022). An investigation into the home environments of 10–14 age group children in cognitive maps. *FSM Scholarly Studies Journal of Humanities and Social Sciences, 19*, 369–397. https://doi.org/10.16947/fsmia.1136517

Çanakçıoğlu, N. G. (2011). *Investigation of the perceptual processes of children living in different social environments in Istanbul by cognitive map method* [İstanbul'da farklı sosyal çevrelerde yaşayan çocukların algısal süreçlerinin bilişsel harita yöntemiyle incelenmesi] [Master's thesis]. Istanbul Technical University.

Cooley, C. H. (1909). *Social organization: A study of the larger mind*. Charles Scribner's Sons. https://doi.org/10.1037/14788-000

Coşkun, D. B., & Kaymaz, S. (2022). Examination of urban space awareness through children aged 7–11. *Design + Theory, 18*(36), 175–196. https://doi.org/10.14744/tasarimkuram.2022.95866

Damayanti, R., & Kossak, F. (2016). Extending Kevin Lynch's concept of imageability in third space reading: A case study of kampungs, Surabaya–Indonesia. *A/Z ITU Journal of the Faculty of Architecture, 13*(1), 57–67. https://doi.org/10.5505/itujfa.2016.36349

Den Besten, O. (2010). Local belonging and "geographies of emotions": Immigrant children's experience of their neighbourhoods in Paris and Berlin. *Childhood, 17*(2), 181–195. https://doi.org/10.1177/0907568210365649

Downs, R. M., & Stea, D. (1973). Cognitive maps and spatial behavior: Process and products. In R. M. Downs & D. Stea (Eds.), *Image and environment: Cognitive mapping and spatial behavior* (pp. 8–26). Aldine Publishing Company.

Doherty, S., & Pellegrino, J. W. (1985). Spatial ability development in children: A cognitive mapping approach. *Journal of Experimental Child Psychology, 39*(2), 215–230.

Fang, J., & Lin, J. (2017). School travel modes and children's spatial cognition. *Urban Studies, 54*(7), 1578–1600. https://doi.org/10.1177/0042098016630513

Gillespie, A. (2010). How culture constructs our sense of neighborhood: Mental maps and children's perceptions of place. *Journal of Geography, 109*(1), 18–29. https://doi.org/10.1080/00221340903459447

Google. (2025). *Google Earth*. https://earth.google.com/web/

Hall, E. T. (1966). *The hidden dimension*. Doubleday.

Hart, R. A., & Moore, G. T. (1973). The development of spatial cognition: A review. In R. M. Downs & D. Stea (Eds.), *Image and environment* (pp. 27–49). Aldine Publishing Company.

Herman, J. F. (1980). Environmental exploration and cognitive map accuracy in children. *Environment and Behavior, 12*(4), 375–385. https://doi.org/10.1177/0013916580123005

İmamoğlu, O. (1979). Preferences and tastes related to housing. In M. Pultar (Ed.), *Environment, structure, and design* (pp. 321–345). Environment and Architecture Sciences Association Publications. (Konutla ilgili tercih ve beğeniler)

Koç, B. (2012). *Cognitive boundaries in spaces designed for children* [Çocuklar için tasarlanmış mekânlarda bilişsel sınırlar] [Unpublished master's thesis]. Istanbul Technical University.

Ladd, G. (1970). Classifying black children's neighborhood maps: A study of spatial categories. *Child Develop-*

ment, 41(1), 123–134.

Lowrie, T., Jorgensen, R., Logan, T., & Harris, D. (2022). Culture and geography: How do primary students map their local environment? *The Australian Educational Researcher, 49*(2), 261–284. https://doi.org/10.1007/s13384-021-00440-0

Lynch, K. (1960). *The image of the city*. MIT Press.

Matthews, M. H. (1983). Environmental cognition of young children: Images of journey to school and home area. *Transactions of the Institute of British Geographers, 9*(1), 89–105. https://doi.org/10.2307/621869.

Mohsenin, M. (2011). *The impact of urban geometry on cognitive maps* [Master's thesis, Massachusetts Institute of Technology]. MIT Libraries.

Oldenburg, R. (1989). *The great good place: Cafes, coffee shops, bookstores, bars, hair salons, and other hangouts at the heart of a community*. Paragon House.

Ormrod, J. E. (2013). *Educational psychology: Developing learners* (7th ed.). Pearson Education.

Öztürk, Ö. (2009). *The concept of home and the perception of the residential environment in children* [Çocuklarda konut ve konut çevresi algısı] [Unpublished master's thesis]. Istanbul Technical University.

Öztürk, Ö. (2015). *Evaluation of housing environment safety in the context of play and movement needs of primary school children: Istanbul, Beylikdüzü case study* [Unpublished doctoral dissertation]. Istanbul Technical University, Graduate School of Science and Engineering. (Oyun ve hareket gereksinimi bağlamında ilkokul çocuklarının konut çevresi güvenliğinin değerlendirilmesi: İstanbul, Beylikdüzü örneği)

Park, J. H., & Kim, M. H. (2012). An analysis of a child's residential environment's cognitive characteristics using cognitive maps. *Journal of the Korean Housing Association, 23*(1), 59–68. https://doi.org/10.6107/jkha.2012.23.1.059

Piaget, J. (1954). *The construction of reality in the child*. Ballantine Books. https://doi.org/10.1037/11168-000

Risotto, A., & Tonucci, F. (2002). Movement autonomy and environmental information acquisition in children. *Urban Studies, 39*(4), 729–745.

Rzhanova, I. E., Alekseeva, O. S., & Fominykh, A. Y. (2020). Gender differences in cognitive indicators in preschool and primary school-age children. *Moscow University Psychology Bulletin, Series 14: Psychology, (2)*, 141–157. https://doi.org/10.11621/vsp.2020.02.07

Seyhan, Ç. (2021). *Urban space imagery in children's cognitive maps: The case of Trabzon Ortahisar district* [Çocukların bilişsel haritalarında kentsel mekân imgeleri: Trabzon Ortahisar örneği] [Unpublished master's thesis]. Karadeniz Technical University.

Thommen, E., Avelar, S., Sapin, V. Z., Perrenoud, S., & Malatesta, D. (2010). Mapping the journey from home to school: A study on children's representation of space. *International Research in Geographical and Environmental Education, 19*(3), 191–205. https://doi.org/10.1080/10382046.2010.496975

Tönnies, F. (1957). *Community and society* (C. P. Loomis, Trans.). Transaction Publishers. (Original work published 1887)

Türel, A., & Gür, E. A. (2019). Effects of primary school's physical environment on children's spatial perception and behavior: The case of Kağıthane, Istanbul, Turkey. *Megaron, 14*(3), 403–416. https://doi.org/10.14744/megaron.2019.18164

Ünlü, A., & Çakır, H. (2002). A study on perception of primary school children in a home environment. *Journal of Architectural and Planning Research, 19*(3), 231–246.

Wadsworth, B. J. (2015). *Piaget's cognitive and affective development theory: Foundations of constructivism* (6th ed.). Pearson Education.

Yavuzer, H. (2003). *Çocuk psikolojisi [Child psychology]*. Remzi Publishing.

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Article

Geometry, material, and construction technique of the belt of Turkish triangles: An innovative architectural and structural solution developed in Anatolia for transitional zone challenges

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Transition zone in Turkish Architecture; transition element; the belt of Turkish triangles; geometry; material; construction technique.

ABSTRACT

Between the 12th and 15th centuries, the belt of Turkish triangles, which was developed as an original solution in the transition from cubic space to the dome in Anatolia, found widespread application as a common transition element from the Seljuk Period to the Principalities and the Early Ottoman Periods. In addition to its structural features, the aesthetic values arising from the rich geometric combinations of the belt of Turkish triangles have played a significant role in its use as a transitional element. In historical buildings, where roofs or walls have been damaged for various reasons, the transitional zones between them often represent the most vulnerable areas, requiring careful intervention. Therefore, a detailed understanding and analysis of the original architectural and structural characteristics of cultural heritage buildings are of primary importance. Although the Turkish triangle belt has been examined primarily from a formal perspective in architectural history, studies that focus on material and construction techniques remain quite limited. In this context, the present study aims to provide a comprehensive analysis of the geometric/formal, material, and constructional characteristics of the transitional zones employing the belt of Turkish triangles in between the 12th and 15th centuries. Accordingly, the construction techniques of different geometric configurations have been modelled in three dimensions. The study is structured in three main stages. First, the geometric/formal features of the belt of Turkish triangles-particularly at surfaces and corners-are examined using the data obtained from literature and field studies. The geometric scheme of the transitional zone is also analysed from various perspectives, including the relationship between the substructure and superstructure as well as facade characteristics. Second, the material and construction technique employed in the belt of Turkish triangles are investigated. Finally, the construction process of different types of the belt of Turkish triangles is modelled step by step and presented in detail. Transition zone with the belt of Turkish triangles, which is composed of variations of plane and triangular prisms, exhibits geometric differences particularly in the corner units. Although the use of stone material in the construction of plane triangles is rarely encountered, the belt of Turkish triangles is predominantly built using brick, often with thick mortar joints between the units. Before the construction of the transitional zone, a single or a few rows of bricks are laid slightly projecting from the wall surface where the wall ends, in order to level the base and define the starting line of the transition zone. Once the height of the transition zone is determined according to the dome span, a wooden centering is prepared to define the base

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line of the dome. Then, depending on the design of the plane or prismatic units, guiding strings are stretched between the brick courses on the wall and the wooden framework of the dome. As the transitional zone is formed by the repetition of a quarter segment, the parts from the corners to the midpoint of each wall are constructed incrementally and simultaneously. First, the units with their base on the wall are laid in a cantilevered manner up to a certain height. Then, the intermediate units whose apex lies on the wall are added, continuing together with the rest of the structure up to the dome's springing line. As a result, the belt of Turkish triangles forms the cubic base into a polygonal form. As the number of triangular units increases, the number of polygonal sides also grows, making the transition to a circular dome base more efficient. The transition from the polygonal base to the circular dome is achieved by means of a few additional rows of bricks forming a border course. One of the key findings regarding the belt of Turkish triangles with prismatic units is that the dimensions or base width of each unit are directly related to the dimensions of the brick material used. Therefore, in belts composed of prismatic units, the number of units increases not merely for aesthetic reasons, but as a structural necessity, since the base of each prism is limited in size.

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INTRODUCTION

In the Medieval period, masonry structures were fundamentally composed of walls, superstructures, and the transitional elements connecting them. In historical buildings, domes and vaults frequently functioned as the superstructure. However, transitioning from a square or rectangular base to a circular dome consistently posed both architectural and structural challenges. To address these spatial and structural discrepancies, architects developed transitional elements that mediate between differing plan geometries.

The use of domes over cubic spaces can be traced back to both the pre-Islamic architecture of the Sasanian period and early Islamic architecture in Iran. Archaeological excavations have uncovered evidence of dome construction dating to antiquity. These early examples were generally small-scale domes employed in modest structures such as houses, granaries, barns, and storage buildings. The limited scale and simplicity of these domes reflect a lack of advanced knowledge regarding transition elements, which are essential for effectively spanning square spaces with circular superstructures (Creswell, 1969; 455-457).

Early solutions to the transition problem included rudimentary techniques such as corbelled masonry. In the western tomb at Amman, for instance, a row of cantilevered stone blocks projects outward at the corners, their upper surfaces shaped to form a circular base for the dome (Figure 1a). In the bath at Abda, a triangular stone element projects from each corner, allowing a transition to a polygonal base (Figure 1b). Similarly, at Umm Az-Zaytun in Syria, a multi-stepped transition from square to circular plan is achieved through two or three rows of projecting stones (Figure 1c).

Depending on regional practices, available materials, construction techniques, and cultural interactions, transition elements evolved into several distinct typologies over time. Broadly, these can be categorized into three principal types: the pendentive, the squinch, and the belt of Turkish triangles[1].

The pendentive is a structural solution that allows for the placement of a dome over a cubic space without requiring an intermediate transition zone. It is typically integrated within the corners of the cube and terminates as the cube itself ends. Pendentives are classified into two main types based on geometric construction: pyramidal and spherical. The pyramidal pendentive transforms the square base into an octagon, upon which additional courses transition to a circular dome base (Figure 2a). Diez (1946; 112) mentioned that these could be enhanced with folded surfaces. A prominent example is the İnce Minareli Madrasa in Konya, where the dome rests on a pyramidal pendentive formed by four folded triangular surfaces (Figure 2b).

Spherical pendentives, often termed *true pendentives*, facilitate a direct transition from a square base to a circular dome. According to Creswell (1969) and Kuban (1998), these can be subdivided based on curvature: one type has a diameter smaller than the dome (Figure 3a), while the other-termed as *shallow dome*-shares the same curvature and diameter as the dome itself (Figure 3b). The latter is not a transition element in the strict sense, as its surfaces are structurally continuous with the dome itself.

The squinch, known as "tromp" in French and "kemerli bingi" in Turkish, employs arches placed diagonally across the corners of a square base to convert it into an octagonal plan. From this octagonal base, additional layers or decorative elements like muqarnas facilitate the transition to a circular dome base. Because the squinch requires a defined transition zone, its use is generally limited to structures with smaller spans to avoid excessive height.

The squinch played a crucial role in early Islamic architecture, especially in Iran (Wilber, 1969). In the Sasanian monument at Firuzabad, squinch vaults were employed to support domes over square chambers (Figure 4a). Pope (1967) describes the difference between the squinch vault and the squinch. The squinch vault involves building diagonal arched courses in each corner that gradually form partial

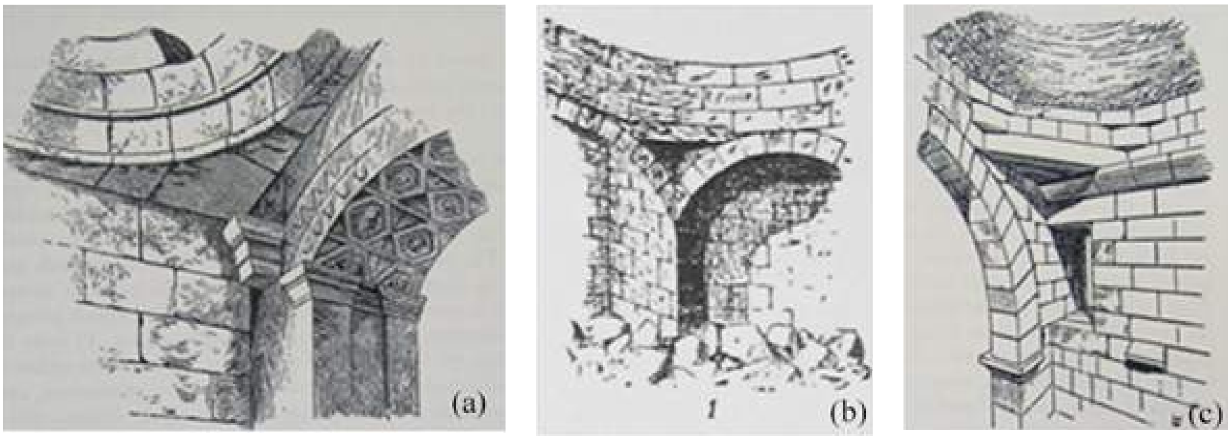


Figure 1. **(a)** Western Tomb in Amman (Creswell, 1969; 456), **(b)** Triangular cantilevered stone piece at the corner of the bath at Abda (Creswell, 1969; 457), **(c)** Umm Az-Zaytun at Syria (Creswell, 1969; 456).

cones, eventually enclosing the space (Figure 4b). In contrast, the squinch technique leaves gaps between these corner structures, which are then filled with horizontal layers that create a circular base to support the dome (Figure 4c).

The belt of Turkish triangles was developed in Anatolia and is therefore known as the "Türk üçgeni" in Turkish (Batur, 1980). It is a distinctive transitional system composed of a band of triangular units, each inclined at varying angles. These triangular surfaces convert a square base into a polygonal form, upon which additional rows of cantilevered masonry allow for the formation of a circular dome base (Figure 5). Like the squinch, the belt of Turkish triangles necessitates a transition belt, and the belt's height increases proportionally with the dome's span.

Although often confused with fan or pyramidal pendentives (Rice, 1961; Hasol, 1995; Ünsal, 1959; Aslanapa, 2003; Boran, 2001, Şenalp & Binan, 2024) (Figure 6a), the belt of Turkish triangles (Figure 6b) represents a unique solution that gained prominence in Anatolian Seljuk, Principality and early Ottoman architecture from the 12th to the 15th centuries. Despite its formal resemblance to other elements, its geometry and construction technique differs significantly (Figure 6b).

The implementation of the belt of Turkish triangles was likely influenced not only by its structural properties but also by the aesthetic and sculptural effects it introduced to interior spaces, thanks to its rich stylistic and geometric forms. Acland (1972) highlights the flexibility of folded sur-

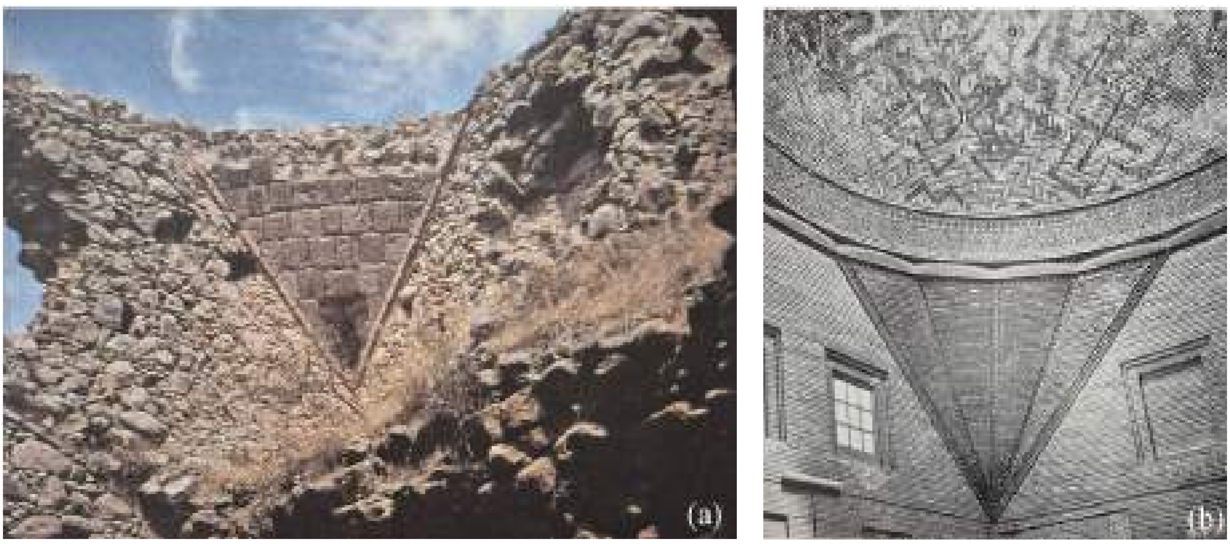


Figure 2. **(a)** Kızıl Han in Peçin (Kolay, 2017; 58) and **(b)** İnce Minareli Madrasa in Konya (Kuran, 1969; figure 105).

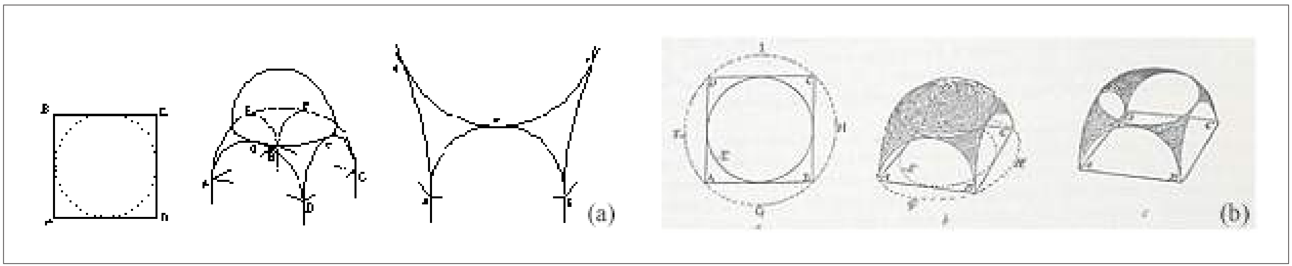


Figure 3. **(a)** Diameter of the pendentive is smaller than the dome, the spherical pendentive (Söylemezoğlu, 1955; 81) and **(b)** diameter of the pendentive is the same with the dome, pendentive or shallow dome (Creswell, 1969; 460).

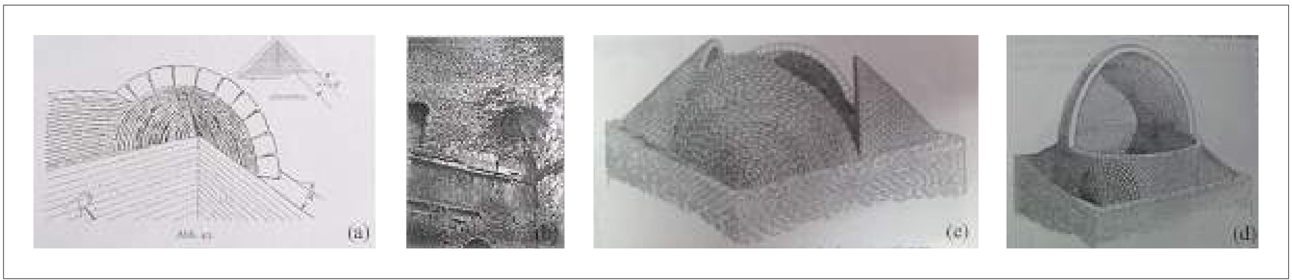


Figure 4. **(a)** Diagram showing inside of squinch (Rosintal, 1912; 32), **(b)** the squinch applied in Firuzabat (Rosintal, 1912; 33), **(c)** diagrams showing the squinch vault and (Pope, 1967; 58), **(d)** the squinch (Pope, 1967; 59).

faces in triangular or prismatic units, which facilitate transitions between different geometries. Turan (1993) stated that the belt of Turkish triangles offers a more uniform load distribution compared to pendentives and squinches. The concentrations of forces perpendicular to the wall plane and the resulting moments acting on walls with the belt of Turkish triangles are lower than those observed with other transition elements. Söylemezoğlu (1955) emphasizes that the transition from a square plan to a circular dome in Seljukid and Ottoman architecture was achieved through the use of 'triangular surfaces', which offer an impressive and aesthetically pleasing volumetric appearance distinct from squinches and pendentives. This elucidates the preference for the belt of Turkish triangles, particularly in the transition zones of bath domes, where interior walls are blind and plain, as observed in structures like Balat Bath, Peçin Bath, Mudurnu Yıdırım, Çakır, and Davud Paşa Baths in Bursa. Furthermore, Kuban (1976) noted that the structural geometric harmony offered by the belt of Turkish triangles in transitioning to fluted or segmented domes made it a preferred choice in numerous prominent baths of the period. Examples include Gazi Mihal, Saray, Yeniçeri, Beylerbeyi Baths in Edirne, and İsmail Bey Bath in İznik.

Despite its structural and aesthetic advantages, the use of the belt of Turkish triangles became unpopular after the 15th century. In Classical Ottoman Architecture, particularly in the works of Mimar Sinan, pendentives were frequently employed to enhance spatial integrity, continuity, and fluidity. Moreover, since pendentives are curvilinear forms like domes, they naturally follow one another and efficiently

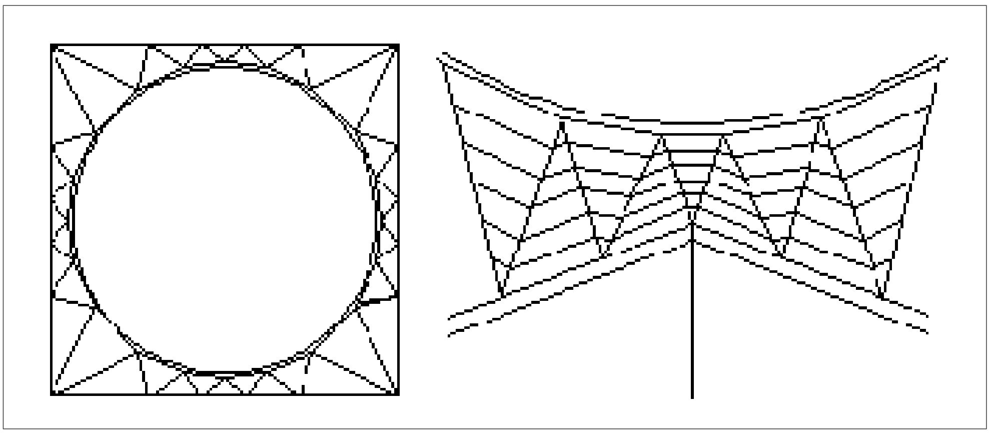


Figure 5. The band of triangles inclined in different angles (Design by Author).

Figure 6. **(a)** The transition element with fan pendentive in the closed courtyard of Karatay Madrasa in Konya (Boran, 2001; figure 539) and **(b)** the belt of Turkish triangles of Alaaddin Mosque in Konya (Bilici, 2016a; 23).

transfer horizontal loads by linking the baldachin support system to the dome without requiring additional intermediary elements (Tuncer, 1984). Conversely, the growing span of domes demanded taller transition zones in the belt of Turkish triangles, while the corbelling systems proved structurally inadequate in resisting lateral forces (Yavuz, 2002; Batur, 1980).

The use of the belt of Turkish triangles was initially observed on the facades of "kümbet", as seen in the Melik Gazi Tomb dating back to 1250 in Kırşehir, marking the transition from a quadrangle plan to a polygonal base in Anatolian Seljukid architecture. Built in 1347, the Güdük Minaret in Sivas features a belt of Turkish triangles on the outside to pass from a square base to a twenty-sided shape. Inside, the transition to the sixteen-sided circular dome base is done using pendentives decorated with stalactites. This shows that different transition elements can be used together in harmony - the belt of Turkish triangles on the outside and a different methods on the inside. (Figure 7a,7b). Subsequently, from the second half of the 12th century to the beginning of the 13th century, it found application in the inner space, facilitating the transition from ground plan level to upper structure plan level (Batur, 1980). Throughout the Seljuk, Principality, and early Ottoman periods, the belt of Turkish triangles found extensive application in various types of buildings, including mosques, masjids, madrasas,

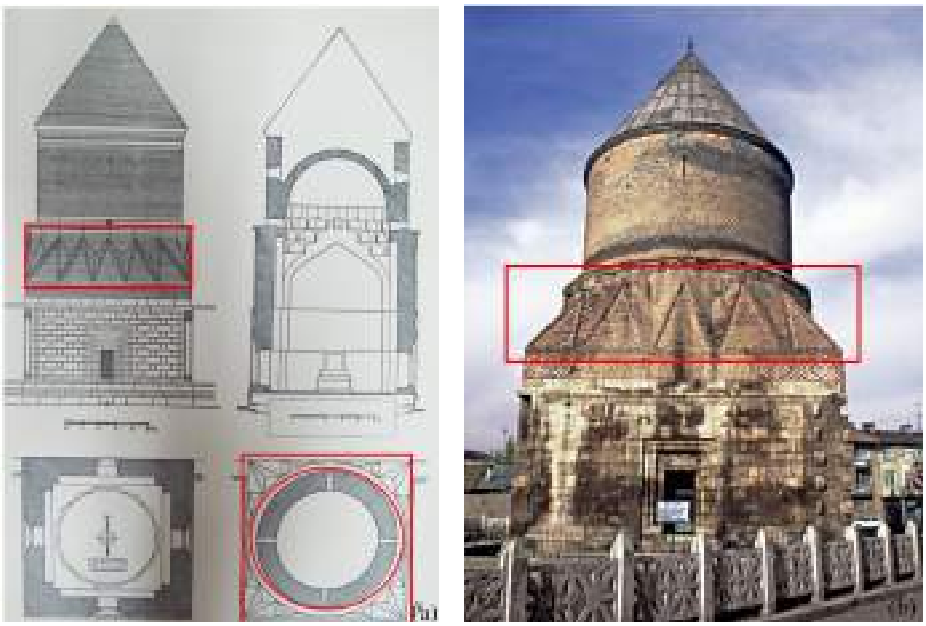


Figure 7. Sivas Güdük Minaret, **(a)** architectural drawings (Gabriel, 1934; 186) and **(b)** facade (Önkal, 1996; 214).

tombs, imarets, and zawiyas. Particularly in single-domed masjids and baths, the belt of Turkish triangles served as a key transition element (Peker & Bilici, 2006). It was also commonly employed to facilitate the transition from the square-planned minaret base to the polygonal body section or from the circular body of the column to the square-planned capital (Uluengin et al., 2001).

The use of belt of Turkish triangles in both interior and exterior spaces is quite similar, as both serve the same purpose: facilitating the transition between square and circular plan geometries. When used on the exterior, the Turkish triangle band is often combined harmoniously with a different transitional element on the interior within the same transition zone. A notable example of this is observed in the Güdük Minaret of Sivas, where the exterior employs a belt of Turkish triangles, while the interior utilizes a different transition element (Figure 7). Therefore, this study specifically focuses on architectural solutions in which the geometric transition - from a square or polygonal plan to a circular dome base - is resolved through the use of belt of Turkish triangles. For this reason, the analysis in this study is centered on the use of belt of Turkish triangles in interior spaces. Exterior uses, including those on tomb façades, minaret bases, and column capitals, are acknowledged in the literature but are not examined in detail within the framework of this research.

Despite the significant number of studies on pendentives and squinches in the history of architecture, research on the belt of Turkish triangles is limited and primarily concentrated on its morphological features[2]. Rosintal's (1912) work on transition elements is an important source that elucidates the fundamental geometrical installation principles of the Turkish triangular transition zones between disparate sections of a building, along with detailing the formal features of some well-known applications of the belt of Turkish triangles. Additionally, Batur's (1980) study, which examines the curved roof covers and transition elements of Ottoman period mosques until the end of the 16th century, holds significance in providing the general characteristics of the belt of Turkish triangles. It also catalogues structures in which the belt is utilized, supported by technical and visual documents such as plans, sections, and photographs. Kolay (2017) examined the construction techniques of buildings from the 14th century Principalities Period, assessing the form, material, and construction technique of the Turkish triangular transition belt in general terms. On the other hand, a recent thesis has predominantly focused on the formal features of the belt of Turkish triangles during specific periods[3]. Lastly, a single type of the Turkish triangular belt, composed of prismatic units, has been geometrically analyzed and parametrically produced in a digital environment, without taking into account materials and construction techniques, and a 1/10 scale solid model of the corner section has been created using robotic techniques (Çağlar et al., 2021).

In this article, beyond the form-based studies typically conducted with a focus on a specific period, building group, or region, the structures from the 12th to the 15th centuries that feature the belt of Turkish Triangles are evaluated as a whole. This is crucial in any maintenance, repair, or restoration work to preserve and transmit the original architectural and structural systems - along with the construction technology of the period in which they were built - to future generations[4]. In this context, while the architectural features of the belt of Turkish triangles are revealed in terms of form/geometry, material usage and construction technique, this study is aimed to reveal the material and construction technique relationship of the different forms of the belt of Turkish triangles, for which there is limited information, with three-dimensional models.

The methodology of this study comprises the following stages of the research. Firstly, the structures from the Seljukid, Principalities and Early Ottoman Periods, which included the 12th and 15th centuries when the belt of Turkish triangles was used, were examined. The geometric varieties on the inner surface and at the corners of the transition zone were evaluated together with their common and unusual applications. In addition, the belt of Turkish triangles between different ground plans-dome-façade organization in the transition zone were examined. Secondly, the material and construction technique used in the belt of Turkish triangles were explained with field studies and literature studies. Finally, three-dimensional models were created to illustrate step by step how the material was used and in what sequence the components were assembled to form each geometric/formal type of the belt of Turkish triangles.

RESEARCH AND FINDINGS

Geometry/Form of the Belt of Turkish Triangles

The belt of Turkish triangles is created by combining consecutive up and down triangle or triangular prism units at different angles along a horizontal alignment. The way these units come together at the corners varies, influencing the entire geometrical and formal arrangement of the belt of Turkish triangles. Kolay (2017) noted that the belt of Turkish triangles that are characterized by its thick plasterwork evolved gradually over time. In the first half of the 13th century, it was constructed with plane triangles, and towards the middle of the century, prismatic elements began to emerge. As a result, the belt of Turkish triangles can be divided into two main groups: those consisting of plane triangles and those incorporating prismatic units. On the other hand, Batur (1980) classified the belt of Turkish triangles into three main categories: the 'triangular belt', consisting of plane triangular surfaces; the belt comprising prismatic triangles; and a group of triangles with units located on the corner. The second group was further subdivided into the 'simple belt,' consisting solely of prismatic triangles, and the 'compound belt', in which pyramids were placed within prismatic triangles. It is important to note that Batur classified the triangular prisms created for decorative purposes inside the squinches at the corners as the third type. However, since the defining feature of the belt of Turkish triangles is its continuation in the form of a band on the drum, wall, or dome skirt, it might be misleading to describe them as a distinct type of the belt of Turkish triangles.

It is possible to categorize the belt of Turkish triangles into two main types based on form and geometry (Table 1). The simplest form of the belt of Turkish triangles consists of triangular planes looking upward and downward (Table 1a). The connection type of triangular planes can vary in two ways at the corner. In the first case, the top point of the triangular plane is at the corner of the wall, and the base side is on the dome (Table 1b). This configuration is observed in examples such as the tomb of the Karatay Madrasa in Konya, in front of the "mihrap"[5] space in the Eski Mosque in Edirne, the tomb of the Sahip Ata complex, the masjid of Yusuf Bin Yakup Madrasa in Çay, the Alaaddin Mosque in Konya (Figure 6b), the winter room of the Sırçalı Madrasa, the Mal Hatun Tomb in Edirne, the Çelebi Sultan Mehmet Madrasa in Merzifon, The tomb of Yusuf bin Yakub in Afyon (Figure 8a) and the Hekim Bath in Tire (Figure 8b).

In the second case, the common side of two adjacent triangular planes looking downward intersects with the corner (Table 1c). Examples include the side spaces of the Karacabey Mosque in Ankara (Figure 8c), the masjid of the Sırçalı Madrasah in Konya and the winter room of Konya Sırçalı Madrasa (Figure 8d). The transition zone may consist of continuous triangular units, and at times, a window opening or a niche can be incorporated in the transition section along the central axis of the wall.

In the second type, the belt of Turkish triangles with triangular prisms can be divided into two subgroups based on geometric complexity. In the simple form (Table 1d), triangular prisms can be oriented upward and downward, referred as the belt of Turkish triangles with "baklava" or "badem"[6] as seen in Mehmet Bey Mosque, Tahtakale Mosque and Tahtakale Bath in Tire (Figure 9a, 9b, 9c, 9d). They can be positioned in pairs, where every two adjacent triangular prisms look in the same direction (Table 1e), as seen in Halil Hayrüddin Paşa Tomb in İznik, Yıldırım Madrasa, Umur Bey Bath, and Yeşil Tomb in Bursa. Similarly, while a pair of the prisms can face downward, one can face upward, as observed in Kurşunlu Mosque in Bergama. In the complex or combined form, the bases of the primary triangular prisms, resting on the wall or the circular dome base, are adorned with smaller decorative triangular prisms, known as the belt of Turkish triangles

Table 1. The geometrical typology of the belt of Turkish triangles in elevation and at the corner

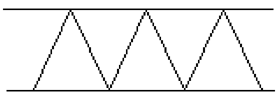
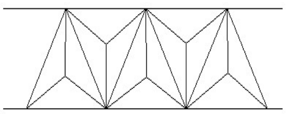
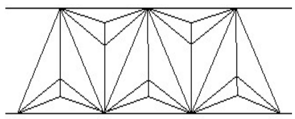
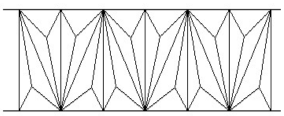
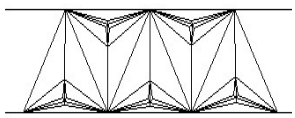
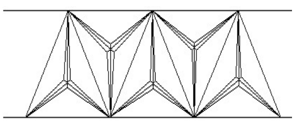
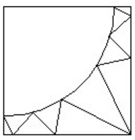
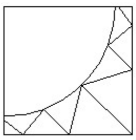
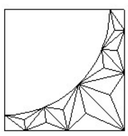
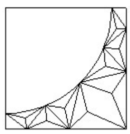
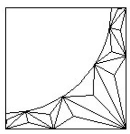
	Belt of Turkish triangles composed of triangular planes	Belt of Turkish triangles composed of triangular prisms: Belt of Turkish triangles with simple triangular prisms *Bademli/Baklavalı Türk Üçgeni Kuşağı*	Belt of Turkish triangles composed of triangular prisms: Belt of Turkish triangles with combined triangular prisms *Göbekli Türk Üçgeni Kuşağı*
Elevation	 (a)	 (d)	 (e)
		 (f)	 (g)
		 (h)	
Corner Types	 (b)  (c)	 (i)	 (k)  (l)

Figure 8. **(a)** The tomb of Yusuf bin Yakub in Afyon (Önkal, 1996; figure 414), **(b)** the Hekim Bath in Tire (Author, 2007), **(c)** the Karacabey Mosque in Ankara (Author, 2007) **(d)** the winter room of the Sırçalı Madrasa in Konya (Kuran, 1969; 215).

with combined triangular prisms[7] as illustrated in (Table 1f). While the center of the decorative prisms projects towards the space, the primary one's recess into the wall through the transition zone, as exemplified in the Tahtakale Bath in Tire and in the entrance and main spaces of Yeşil Mosque in Bursa (Figure 9c, 9d, 9e, 9f). In the belt of Turkish triangles with "badem" or combined triangular prisms, the sides of large triangular prisms and small decorative prisms, intersecting at the center of the primary triangular prisms, can be ornamented with linear bordures (Table 1g, 1h), resembling a three-armed star shape, as seen in Muradiye Mosque, Tavuk Pazarı Bath, and also intersecting at the center of the small triangular prism, as observed in Tahtakale Mosque in Tire and Yeşil Mosque in Bursa (Figure 9c, 9d, 9e, 9f).

At the corner of prismatic triangles, three general types of geometric solutions are observed. In the first type (Table 1i), the common side line of two adjacent triangular prisms looking downward is located at the corner of the wall, as seen in the tepidarium of the Tahtakale Bath in Tire, at the entrance of Orhan Gazi Mosque in Bursa, Selçuk Bath, or in the main space of Yeşil Mosque (Figure 9c, 9d, 9e,9f). The second type is very similar to the previous one, with the only difference being the absence of a corner line (Table 1k). A "badem" with flat surface projects from the corner of the wall to the circular dome base as observed in Nilüfer Hatun İmareti, Yeşil Mosque in İznik, Gazazhane Mosque in Tire and Devlet Hatun Tomb in Bursa (Figure 9g, 9h). In the third type, as seen in Mehmet Bey and Tahtakale Mosques in Tire, the triangular prism facing upwards is positioned between the wall corner and the base of the dome (Figure 9a, 9b) and (Table 1l).

In addition to the common types found in the belt of Turkish triangles, there are also unusual applications. The Leyse (Pir Ahmet) Mosque in Tire is an extraordinary example consisting of the combination of two downward-facing triangular prisms and one upward-facing plane triangle (Figure 10a). Another unconventional arrangement is seen in the Hamzabey Mosque in Bursa, where the prismatic units are arranged in the form of triangular prisms with a truncated top, deviating from the usual patterns. In the main space of the Muradiye Mosque in Bursa, the belt of Turkish triangles is composed of "badem" standing side by side and triangular prisms that resemble mirrored pairs of each other (Figure 10b). Another unique application is found in the Green Tomb in Bursa, where the region between the "badem"s standing next to each other is filled with plane triangles (Figure 10c).

There are also various types of corner solutions elaborated with triangular prisms in the Turkish triangular transition zone. While Yalınayak Masjid in Tire has four adjacent triangular prisms facing the same direction at the corner, the surfaces of the triangular prism at the corner were also differently treated in Parmaklı Masjid in Bergama (Figure 11a, 11b). Especially in baths, in contrast to the blind and plain wall surfaces, the space becomes as impressive as possible owing to the belt of Turkish triangles. For example, in the "halvet"[8] of Tahtakale Bath, each surface of the triangular prism located in the corner has been treated in such a way that it seems to be formed by the interlocking of four smaller triangular prisms adjacent to each other (Figure 11c). In Tavuk Pazarı Bath in Bursa, there is six armed star shape consisting of six triangular prisms at the corner (Figure 11d). On the other hand, in the Saray Bath in Edirne, the corner of the belt of Turkish triangles is composed of squinch with stalactites (Figure 11e).

Although the belt of Turkish triangles is typically located in a single transition zone, there are also examples that are positioned in a double transition zone (Figure 12). It can be composed of triangular planes, as seen in Beyhekim Masjid in Konya and Hamza Bey Mosque (Figure 12a, 12b), or triangular prisms, as observed in Bursa Muradiye Mosque, Bergama Debbağlar Bath (Figure 12c), Peçinler Bath, and Bursa Ördekli Bath. In the east iwan of Hamza Bey Mosque in Bursa, the double line of the Turkish triangular transition zone consists of triangular planes. The lower and upper parts of the belt of Turkish triangles are positioned as mirrors of each other. In other words, triangular planes looking up are situated on top of the triangular planes looking down. The Hoca Tabip (Aynalı) Mosque with a double line of Turkish triangular transition zone is an extraordinary example in terms of the combination of triangular prisms at the lower level with the second line of triangular planes, which also project or recess according to the folding dome (Figure 12d)

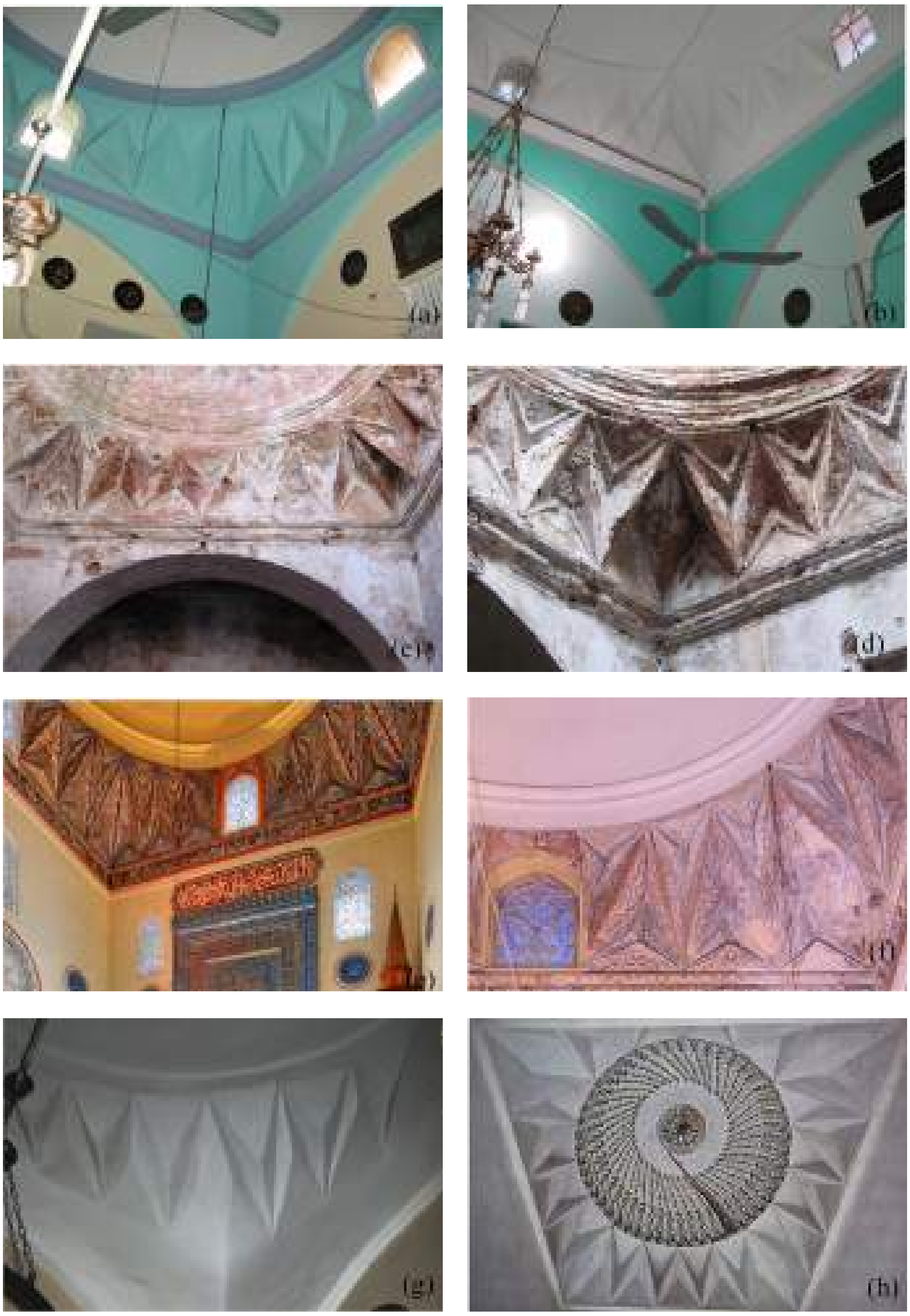


Figure 9. **(a)** Mehmet Bey Mosque, Tire (Photo by Author), **(b)** Tahtakale Mosque, Tire (Author, 2007), **(c, d)** Tahtakale Bath, Tire (Author, 2007), **(e, f)** main space of Yeşil Mosque with the ornamented belt of Turkish triangles, Bursa (İrteş, 2021; 75, 83), **(g)** Gazazhane Mosque in Tire (Author, 2007) and **(h)** Devlet Hatun Tomb in Bursa (Kuban, 2007; 155).

Turkish Triangular Transition Zone Between Different Ground Plans and the Dome

The belt of Turkish triangles offers rational solutions and provides considerable flexibility in solving the transition from different plan geometries to the dome. Namely, differentiating the inclination angles of triangular units according to their position in the transition zone, increasing their number, or adjusting the height of the transition zone can be counted among the most frequently encountered solutions. Based on the number of triangles in a quarter of the Turkish triangu-

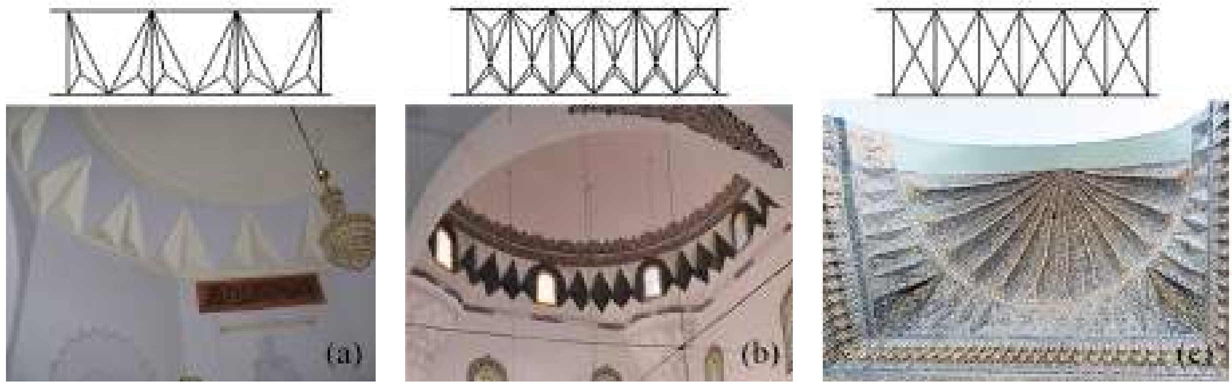


Figure 10. **(a)** Leyse (Pir Ahmet) Mosque, Tire (Author, 2007); **(b)** Bursa Muradiye Mosque (Türkiye Kültür Portalı, n.d.), Bursa; **(c)** Yeşil Tomb (Xodjoyeva, 2019; 41).

lar transition zone at each corner, a polygon-based plan is formed, for which the number of edges is multiples of four, such as eight, twelve, and sixteen, before reaching the circular dome base. As the number of triangles increases, the base on which the dome sits becomes closer to a circular form than a polygonal one. In this context, it is possible to basically divide the belt of Turkish triangles into three groups in terms of the relationship between the ground and upper structure.

The first type facilitates the transition from a square-plan base to a circular, octagonal, dodecagon, hexadecagon, or a polygonal base with twenty or more sides, upon which the dome rests (Table 2). While numerous examples of this type exist, some notable instances include: transitioning from a square plan to an octagonal dome base, as seen in the Yeniceköy Bath in Tire (Table 2a1); transitioning to a dodecagon dome base, observed in the Hekim Bath in Tire (Table 2a2); transitioning to a hexagonal dome base, visible in various locations such as the main space of the Murad Paşa Mosque in İstanbul, the main iwan, tomb, and rooms on both sides of the Taş Madrasa in Akşehir, the Sahib Ata Tomb in Konya,

Figure 11. Corner details of the belt of Turkish triangles; **(a)** Yalınayak Masjid, Tire (Author, 2007), **(b)** Parmaklı Masjid, Bergama (Şaşmaz, 2025), **(c)** Tahtakale Bath, Tire (Author, 2007), **(d, e)** Tavuk Pazarı Bath, Bursa and Saray Bath, Edirne (Kula Say, 2007; 205, 154).

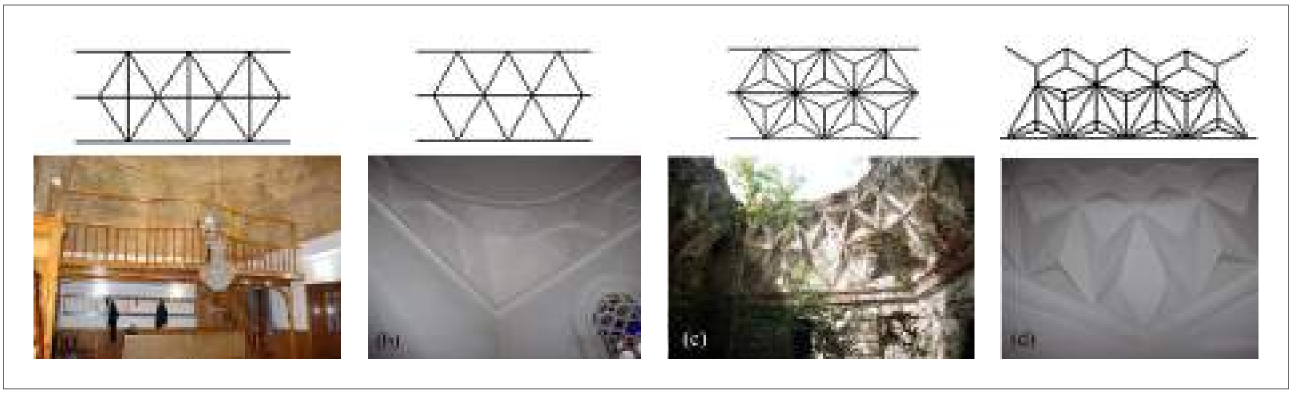
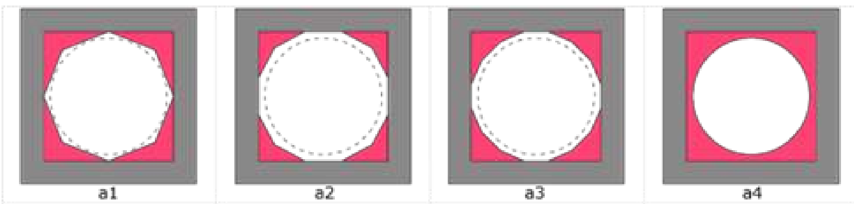
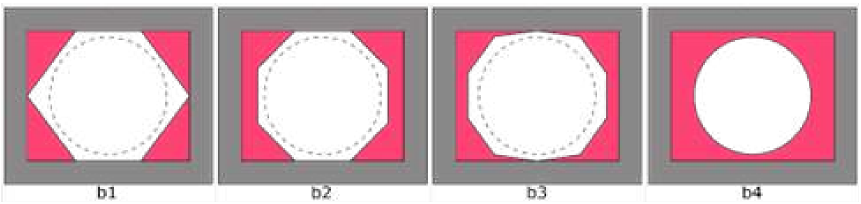
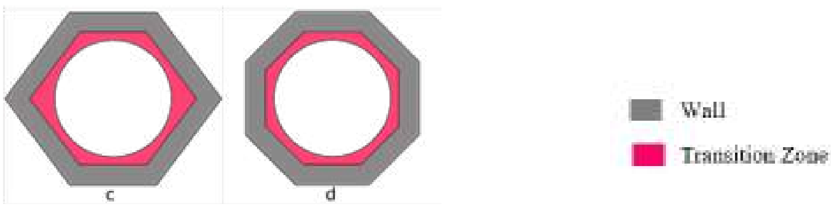


Figure 12. Triangular planes and prisms with double transition zone; **(a)** Beyhekim Masjid in Konya (Çolak, 2025) **(b)** Hamza Bey Mosque in Bursa (Şimşek, 2010; 316), **(c)** Debbağ Bath in Bergama (Kula Say, 2007; 164), (d) Hoca Tabip (Aynalı) Mosque in Bursa (Şimşek, 2010; 362).

the masjid of the Gök Madrasa in Sivas, the Nureddin İbn-i Sentimur Tomb in Tokat, and in front of the *mihrap* space of the Eski Mosque in Edirne (Table 2a3). Additionally, such transitions extend to a twenty-sided dome base, exemplified in the front of the "mihrap" space of the Alaaddin Mosque in Konya and the Yavaşca Şahin Mosque in İstanbul. Moreover, they extend further to a twenty-four-sided dome base, as seen in the women's section of the Tahtakale Bath in İstanbul, and even to a twenty-eight-sided dome base, showcased in the Hacı Özbek Mosque in İznik (Table 2a4).

The second form is employed to transition from a rectangular plan to a hexagonal, octagonal, hexadecagon, twenty-sided polygonal base, or a circular base upon which the dome rests (Table 2b1, 2b2, 2b3, 2b4). In such applications, due to the dome opening often aligning with or being close to the structure's short side, the triangular units on the shorter side protrude more and are inclined to close the gap between walls and the dome. Examples of this transition achieved through the use of the belt of Turkish triangles include: from rectangular planned structures to an octagonal dome base, showcased in Nilüfer Hatun in İznik; to dodecagonal and hexagonal dome bases, as observed in the Yıldırım Bath in Mudurnu; to a dodecagon dome base, evident in the narthex of the Karahasan Mosque in Tire; to octagonal, dodecagonal, and hexagonal dome bases, as seen in the Karacabey Bath in Ankara; to a hexagonal dome base, displayed in the side domes of the İvaz Bey Mosque in Manisa; and finally, to the base of a twenty-cornered dome, exemplified in the dressing area of the Demirtaş Bath in Bursa.

Table 2. Geometric relationship between plan layout and the base of the dome with belt of Turkish triangles

Transition alternatives in square shaped Space	
Transition alternatives in rectangular shaped Space	
Transition alternatives in hexagonal or octagonal plan	

The third form involves transitioning from an octagonal or hexagonal plan base to a circular dome base. For instance, the middle section of the portico of Nilüfer İmaret in Bursa employed double transition elements: the first transitioned from a rectangular plan to a hexagonal base using large triangular units, while the second transitioned from the hexagonal base to a circular dome base. Similarly, various locations such as the Leyse (Pir Ahmet) Mosque, the dressing hall of the Tahtakale Bath in Tire, Yeşil Tomb in Bursa, and the cold area of the Davut Paşa Bath in Bursa utilized the belt of Turkish triangles for transitioning from octagonal spaces to circular dome bases. The Cem Sultan Tomb in Bursa also showcases a transition from an octagonal-planned space to a circular dome base (Table 2c, 2d).

The belt of Turkish triangles serves not only to facilitate transitions from regular geometries but also to adapt irregular ground plans to polygonal bases supporting domes as in the Parmaklı Masjid in Bergama (Figure 13a). Furthermore, builders have demonstrated exceptional skill in dealing with rectangular planned spaces. Here, the space is initially converted into a square plan by utilizing arches on one or both short sides. Subsequently, the belt of Turkish triangles is employed to transition to a circular dome base. This technique is evident in structures such as the tomb in Tokat Gök Madrasa and the adjacent rooms on either side of the main iwan in Konya Sırçalı Madrasa (Figure 13b, 13c).

The belt of Turkish triangles can be used as a part of double transition zone. Initially, pyramidal pendentives facilitate the transition from a square to an octagonal plan base. Following this, the belt of Turkish triangles aids in the transition to a circular dome base (Table 3a, 3b, 3c). This technique is exemplified in various structures such as the central space of Demirtaş Mosque, the tepidarium of Demirtaş Bath, the main iwan of Yıldırım Madrasa, and Yıldırım Hospital (Darüşşifa) in Bursa.

The Façade Organization in the Turkish Triangular Transition Zone

The belt of Turkish triangles requires a transition zone that can be situated either within a drum or embedded inside the wall without a drum. In both scenarios, the design of the Turkish triangular transition zone significantly influences the organization of the facade. The reflection of the Turkish triangular transition zone onto the facade can be categorized into three main types (Table 4).

The simplest among these is the drumless application (Table 4A, 4A1), where the dome emerges directly behind high walls as in the Sırçalı Masjid in Konya and the Beçin Yelli Mosque in Muğla (Table 4a, 4b), that was mostly used in the Seljuk period. Later, during the Principalities and the Ottoman period, the use of octagonal drum was observed.

In the second type, sloped wall pieces used at the corners of the drum serve as retaining walls (Table 4B, 4B1) for structural support in early periods. In these cases, both the drum and walls maintain the same level on the facade. At corner regions where the slope towards the dome is most significant within the transition area, external buttress support often becomes necessary alongside the walls as seen in the Hacı Özbek Masjid in İznik and the Kumacık Bath in Amasya (Table 4c, 4d). This additional support addresses the high pressure and tensile forces transferred from the top to the bottom.

In the third type, the primary factor influencing the exterior reflection of the belt of Turkish Triangles is the varying wall thickness, extending from the wall to the top cover. There's a direct correlation between the dome's thickness and its span, leading to a proportional increase in the dome's section, drum and the main walls as the opening expands (Reyhan et al., 2013). Kuban (2007) highlighted an average ratio of 1/10 between the wall thickness and the dome opening. This gradual increase is visible in the drum part forming the transition region, highlighted by the presence of eaves in numerous structures between the walls and the drum (Table 4C, 4C1, 4C2, 4C3, 4C4). These eaves, which delineate the

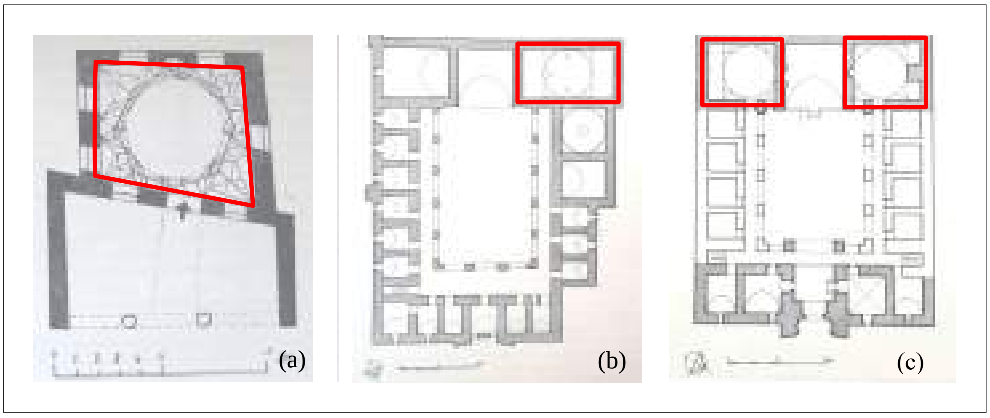


Figure 13. **(a)** Parmaklı Masjid in Bergama (Bayatlı, 1956; 23), **(b, c)** Gök Madrasa in Tokat and Sırçalı Madrasa in Konya (Kuran, 1969; 74, 99).

Table 3. Double transition zone: (a) Plan layout, (b, c) pyramidal pendentive and belt of Turkish triangles with triangular plane and triangular prism.

(a) (b) (c)

Wall — Pyramidal pendentive — Band of Turkish triangles

wall and the drum, can either be a straight line, observed in structures like the Muradiye Mosque in Bursa, the Yeşil Mosque in İznik, and the Ayas Ağa Mosque in Amasya (Table 4e, 4f, 4g), or they may gradually continue based on the positioning of the buttresses supporting the corners, as seen in the Acem Reis Mosque in Bursa (Table 4h).

Particularly during the Principalities Period, one of the commonly encountered architectural features is the use of a double row outer drum, exemplified in structures like the Rum Mehmet Pasha, Narin, Tahtakale, Gazazhane, Karahasan, and Kara Hayrettin (Güdük Minaret) Mosques in Tire. Kolay's (2017) findings suggest that in such instances, the horizontal plane where the two drums meet forms the base or skirt of the dome, marking the starting point of the dome structure (Figure 14). Additionally, it's noted that the lower levels of the outer drum align with the Turkish triangular transition zone.

This section presents a systematic classification of façade configurations related to the transition zone in which, Turkish triangles are used. The classification into three façade types reveals not only stylistic preferences but also structural responses to geometric and spatial needs across periods. By identifying consistent patterns - such as the presence or absence of drums, the role of buttresses, and the proportional relationships between wall thickness and drum - this analysis establishes a foundation for understanding how form and construction logic intersect. These findings pro-

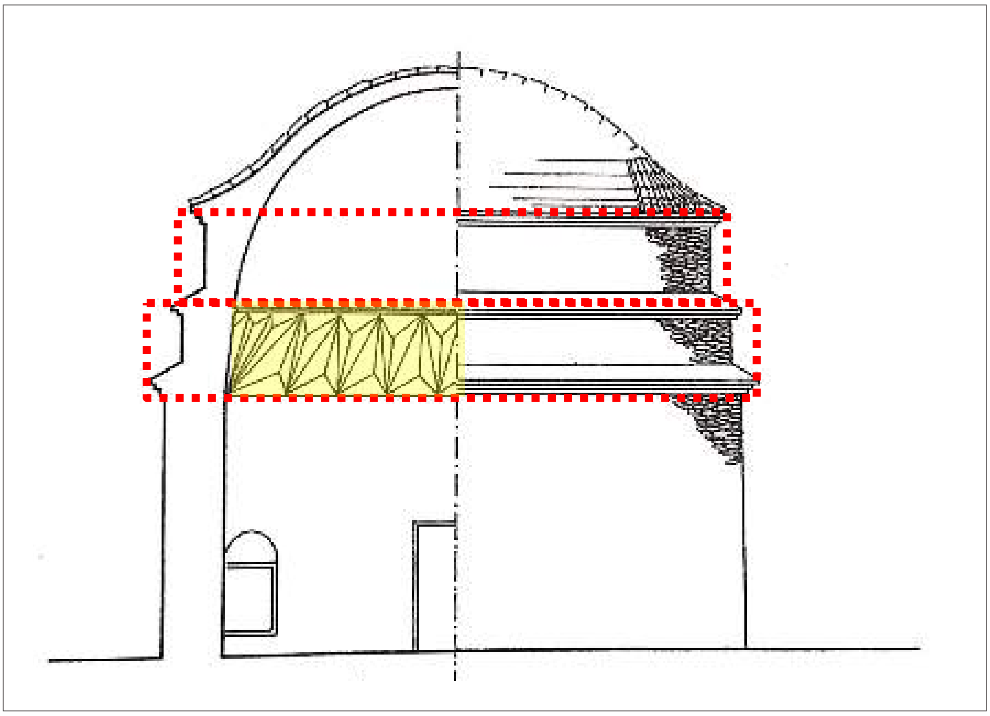
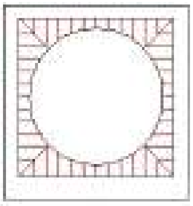
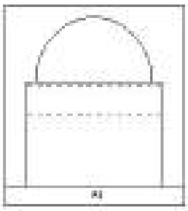
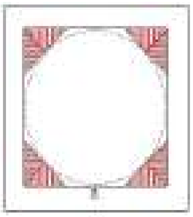
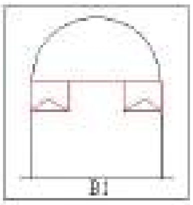
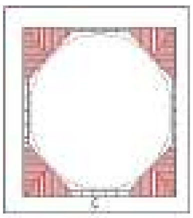
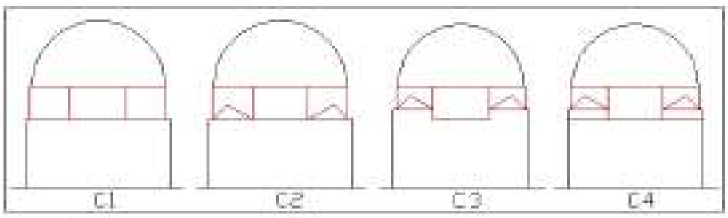
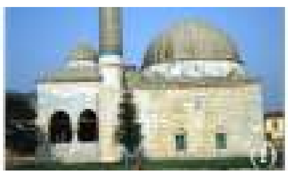


Figure 14. Karahasan Mosque in Tire (Kolay, 2017; 107).

Table 4. (a) Sırçalı Masjid in Konya (Bilici 2016b; 470), (b) Beçin Yelli Mosque in Muğla (AA, n.d.a), (c) Hacı Özbek Masjid in İznik (SALT Research, n.d.a), (d) Kumacık Bath in Amasya (Yarar, 2020; 189), (e) Muradiye Mosque in Bursa (SALT Research, n.d.b), (f) Yeşil Mosque in İznik (SALT Research, n.d.c), (g) Ayas Ağa Mosque in Amasya (Tanman, 1991; 202) and (h) Acem Reis Mosque in Bursa (SALT Research, n.d.d).

Plan Layout	Facade
 A	 A1
	 (a)  (b)
 B	 B1
	 (c)  (d)
 C	 C1 C2 C3 C4
	 (e)  (f)  (g)  (h)

vide essential groundwork for the subsequent discussion on construction techniques, where the physical realization of these morphological choices will be explored in detail.

MATERIAL USAGE AND CONSTRUCTION TECHNIQUE IN THE TURKISH TRIANGULAR TRANSITION ZONE

Material Usage

The belt of Turkish triangles is usually constructed with brick and mortar, and rarely with stone as in Yanköy İçkale Masjid and Vacidiye Madrasa (Figure 15a, 15b), a choice made due to brick's suitability in forming narrow surfaces. However, there are instances where both brick and rough cut or rubble stone were combined in constructing the belt of Turkish triangles, as seen under the plaster in the damaged parts of the transition zone like the Molla Arap Mosque (Figure 15c), Yalınayak Masjid (Figure 15d)), the Tahtakale Bath (Figure 15e) and Karagazi Bath (Figure 15f) in Tire, and the Selçuk Hatun Masjid in Edirne. This combination results in stronger connections between the long stones and the core of the wall in the transition zone as the triangular units project into space (Figure 15c). Batur (1980) observed that the material of the inner part of the transition element corresponds to that of the dome, while the exterior of the drum aligns with the material of the walls.

While the belt of Turkish triangles was generally plastered, there are remarkable exceptions with unplastered buildings showcasing regular brickwork, such as the Ulaş Baba Tomb

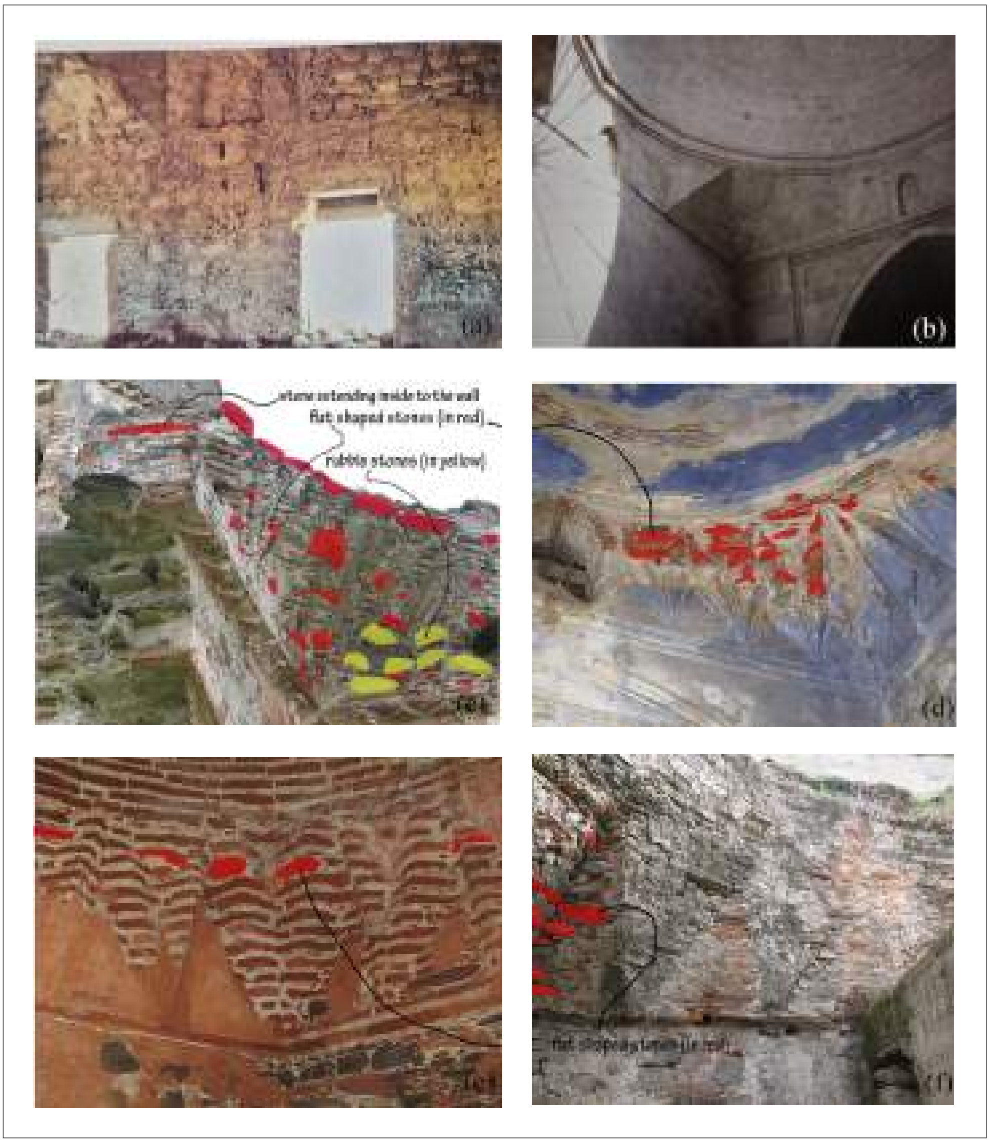


Figure 15. Stone usage; **(a)** Yanköy İçkale Masjid in Antalya (Boran, 2001; foto 224), **(b)** Vacidiye Madrasa in Kütahya (Kolay, 2017; 59), brick and stone hybrid usage; **(c)** Molla Arap Mosque, **(d)** Yalınayak Masjid, **(e)** Tahtakale Bath and **(f)** Karagazi Bath in Tire (Author, 2007).

and the winter classroom of the Sırçalı Madrasa in Konya. Notably, the Vacidiye Madrasa in Kütahya is among these exceptional structures where the surfaces of plane triangles, constructed with stone, were intentionally left unplastered. Önkal (1996) noted that when stone is employed for the triangular belt, as seen in the Seyid Şeref Tomb in Kayseri, the final dressing of the triangular surfaces is executed after the blocks are laid.

The use of bricks varied in size and shape across different sections of buildings in various periods. Tunay (1984), in examining brick use in Byzantine architecture, highlighted size differences ranging between 20 cm and 40 cm, differing not only across periods but also within structures within the same era. During the early Ottoman Period, brick sizes resembling Byzantine dimensions, 14x28 cm and 30x30 cm with a thickness of 4 cm (rarely 4.5 cm), were common (Kutlu, 2017). In the Ottoman Period, typical brick sizes observed in domes were noted as 39–40 × 27–28 × 4–4.5 cm for full bricks and 30–32 × 21–24 × 3–4.5 cm for half bricks, (Reyhan et al., 2013). Meanwhile, the vault of the Süleymaniye Complex used 35×35×4.5 cm full bricks and half bricks (Kolay, 2016). Diri Akyıldız (2018), in a study of the construction technique of Edirne baths from the 14th and 16th centuries, specified that the main structure of transition elements was built using bricks and half-length bricks with dimensions of 27.5×27.5×4-4.5 cm and 24×27.5×4-4.5 cm, respectively. Additionally, bricks with dimensions of 19-20×19-20×4-4.5 cm were used in horizontal and vertical alignments. Horizontally, bricks were used in belt of Turkish triangles, pendentives and rings, while both vertical and horizontal alignments were employed in muqarnas.

Standard brick sizes and shapes are commonly used for smooth surfaces such as walls or domes. Conversely, the belt of Turkish triangles, particularly those with “badem” and combined triangular prisms, exhibit complex arrangements of triangular prisms with folding surfaces that directly influence the material’s shape and size. To achieve the desired shapes for these prisms, bricks may have been divided or trimmed with specific adjustments, allowing them to conform to the varying shapes and bends dictated by the transition zone’s geometry, both externally and internally within the wall.

Özdural's (1996) study on muqarnas details methods of dissecting and composing forms to create diverse ornamental patterns. For instance, he demonstrates various approaches for composing figures by dividing a square into triangles, rectangles, hexagons, and decagons (Figure 16). Adam (1994) points out that in Roman architecture brick was deliberately cut into triangular pieces and was often used in walls in triangular form as in the Pompeii’s masonry walls. Although the brick was used in the whole square form, trimming was a widely used technique in order to help in positioning and to line up the corners. In addition, the insertion of the corner of the triangle into the mortar in the core of the wall creates a stronger bond than the regular bricklaying. Especially in constructing the belt of Turkish triangles with triangular prisms, the focus lies on dense mortar and the expertise of the master, rather than standard material sizes. Since the size or shape of the material changes according to the geometry of the belt of Turkish triangles.

Construction Technique

There is limited information about the construction technique of the belt of Turkish triangles. The fundamental questions in regards to the construction technique are how such precise forms were achieved in the triangular elements, whether any specific geometrical formulas were applied, how materials were positioned within complex geometries, and whether masons employed any form of formwork. Additionally, understanding the sequence in which triangles with intricate shapes were constructed is pivotal. To shed light on these queries, examinations are conducted on damaged transition zones where materials are exposed due to collapse or plaster loss. Insights are also drawn from existing literature that explore the construction techniques related to the geometry of the belt of Turkish triangles.

It’s conceivable that masters might have utilized molds to shape the complex triangular units and prisms, ensuring a smooth surface or holding them in place, particularly at the corners where the transition zone’s largest openings exist. However, in the belt of Turkish triangles, plaster has conventionally been employed to achieve a smooth surface (Figure 17a, 17b), with rare exceptions like the Vacidiye Madrasa in Kütahya and the Sırçalı Madrasa in Konya.

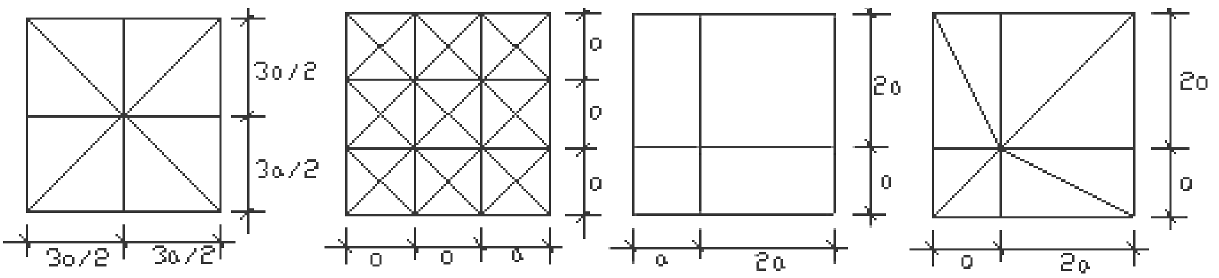


Figure 16. Dividing the square shape brick into smaller pieces (Adam, 1994; 147).

Examining damaged structures such as the Molla Arap Mosque, Karagazi Bath, and Tahtakale Bath in Tire reveals rough brickwork forming triangular prisms beneath the plaster (Figure 17c, 17d). This contrasts with the smooth appearance of plastered surfaces (Figure 17a, 17b). These findings discount the use of molds and emphasize the significance of thick mortar between bricks. This mortar is crucial in shaping the triangular prisms precisely and compensating for stylistic imperfections caused by dividing and trimming the bricks (Figure 17d).

While brick appears to be the primary building material used in the zone of Turkish triangles, a closer examination of certain structures, such as the Molla Arap Mosque, the Yalıayak Masjid and the Tahtakale Bath, reveals a hybrid use of both brick and stone. In these examples, craftsmen deliberately incorporated long and flat rough cut stone pieces or rounded rubble stone alongside bricks, either irregularly distributed within the triangular units (Figure 15c, 15d) or arranged in specific horizontal courses (Figure 15e, 15f). These stone elements were often integrated into the brick courses, not necessarily for aesthetic precision (as these areas would later be plastered), but rather for practical reasons such as material availability or constructional convenience. For example, in the Karagazi Bath in Tire, while brick is commonly observed on the surface areas of the transition zone-where the inclination toward the dome is relatively low-stone appears to have been predominantly used in the plane triangles at the corners, where the corbelling projection is more pronounced (Figure 15f). In some instances, the flat stones may have served to anchor the triangular units more firmly into the wall mass, enhancing structural integration.

The integration of stone materials is particularly evident in the corbelled parts, suggesting that these stones were deliberately positioned within the inner courses to stabilize the units and align with the brick layering. Therefore, it is appropriate to consider the belt of Turkish triangles as a structurally hybrid system in certain applications, where brick is predominant but stone is used as a reinforcing or stabilizing element as seen in the wall section of the Molla Arap Mosque (Figure 15c). This hybrid construction strategy also implies that masons employed flexible techniques rather than a strictly uniform method.

Before delving into the construction of the belt of Turkish triangles, establishing the relationship between the walls and the dome is necessary. In the critical corner regions, where load transfer from the dome to the walls is most crucial, the triangular units play a vital role in safely distributing these loads by elevating the height of the transition region (Figure 18). As the dome opening expands, the height of the transition zone increases accordingly. An observed ratio of 1/4 to 1/5 exists between the height of the transition zone, featuring the belt of Turkish triangles, and the size of the dome opening.

Figure 17. **(a)** Beçin Yelli Mosque (Yurt Haberleri, n.d.), **(b)** Hekim Bath in Tire (Author, 2007), **(c)** Karagazi Bath in Tire (Author, 2007), and **(d)** Tahtakale Bath in Tire (Author, 2007).

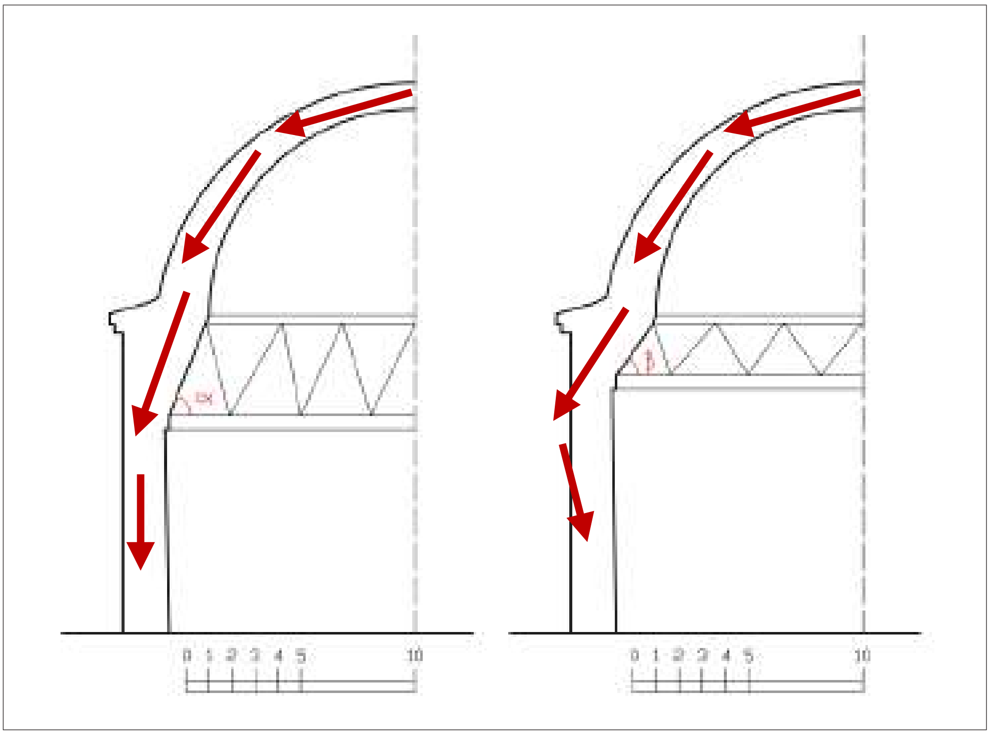


Figure 18. The belt of Turkish triangles with different heights and load transfer (Design by Author).

It should be noted that borders, consisting of two or three rows of bricks positioned to protrude a few centimetres above and below the transition zone, indicate the use of scaffolding during construction (Figure 17a, 17b, 17c, 17d). While the border between the wall and the triangular units ensures a smooth surface for the transition zone, the border on the triangular units facilitates the transition from the polygonal base formed by the belt of Turkish triangles to the circular dome base (Figure 9, 10, 17, 19).

Plane or prismatic triangles are constructed using the corbelling system, employing bricks and thick mortar between them. While there is limited information about the method used in constructing triangular units, Kolay (2017) states that the process begins at the corners due to their structural significance. The resulting triangular units are connected to each other at the midpoint of the transition zone. Şimşek (2010) suggests that when the distance between the walls and the base of the dome is large and the height of the transition zone is low, triangular molds are created in the corners that protrude the most. In such cases, there is no need for a formwork as the middle point of the wall is approached.

Undoubtedly, starting from the corners is crucial to minimize construction errors, considering the role of corners in load transfer for the dome and the necessity of addressing corner areas as a distinct design problem. With consecutively facing triangular units in the belt of Turkish triangles, it is essential initially to construct the triangles located at the corners and along the wall base, as their early stabilization enables the central units to be placed securely. Subsequently, elevating the triangles together using the corbelling system becomes possible. When laying the brick rows of triangular units, it's crucial to shape the material to extend into the wall as much as possible, ensuring a firm fusion with the wall. In certain applications, such as the Molla Arap Mosque, the placement of long flat stones between the rows of bricks reinforced the fusion of triangular units with the core of the wall in the transition zone (Figure 19b). Following the construction of the triangular units, a border section is created with several rows of bricks to achieve a smooth circular base before progressing to the dome.

Additionally, it should be noted that in some Turkish triangular transition zones, an amphora or pipe application may be encountered. Whether they are flat triangles, as seen in the Beçin Yelli Mosque (Figure 19a), or prismatic triangles, as observed in the Molla Arap Mosque in Tire (Figure 19b), amphoras with a diameter of about 20-30 cm are placed in the middle of the triangular units with their open mouths on the surface. Kolay (2017) discussed the use of hollow amphoras or cubes, called *lightening cubes*, to reduce the weight of a building. Atay & Gül (2020) also noted that amphoras can be used in various areas such as super structures, transition elements and flooring to lighten the load of a building, as well as for acoustics or ventilation.

After completing the construction of the transition zone, the front faces of the bricks are trimmed where necessary, according to the folding angle of the triangular units. Finally, the application is completed with plaster, paint, or

Figure 19. **(a)** Beçin Yelli Mosque (Yıldız, 2025), and **(b)** Molla Arap Mosque in Tire (Author, 2007).

decoration. Plastering also serves to conceal craftsmanship faults on the surfaces.

In some applications, the embossed decorative motifs seen on the surface of the belt of Turkish triangles could have been achieved with moulds during plastering. On the other hand, extraordinary surface treatments, such as a single row of projecting bricks placed in the direction of the edge lines of the triangular units during plastering, can be encountered, as seen in the İsmail Bey Bath in İznik.

MODELLING OF THE DIFFERENT GEOMETRIES OF THE BELT OF TURKISH TRIANGLES

When examining the relationship between geometry and construction techniques, despite the existence of extraordinarily complex shapes, it becomes evident that the most prevalent types within the realm of the belt of Turkish triangles include triangular planes, simple triangular prisms known as the belt of Turkish triangles with “badem” and combined triangular prisms (Table 1). In the category of combined triangular prisms, where smaller triangular prisms, known as “göbek”, are positioned on the base surfaces of the main triangular prisms, they can be formed either by projecting bricks to create the smaller triangular prisms or by employing a dense plaster containing thick brick and tile pieces. As the construction technique for the belt of Turkish triangles with “badem” is fundamentally similar to that of the belt with combined triangular prisms, the variations between the two primary types-the belt of Turkish triangles consisting of simple triangles and triangular prisms-are meticulously analysed through 3D modelling (Table 5a).

When generating 3D models for the construction technique of the belt of Turkish triangles, certain assumptions were made based on examples in the literature. These considerations encompassed factors such as space size, the height of the transition zone, dimensions of triangular and prismatic units, as well as material size and mortar thickness. In the belt of Turkish triangles, comprising plane triangles, a square space with a side length of 3 meters was utilized, whereas in types with prismatic triangles, a square space with a side length of 3.5 meters was chosen, accounting for the geometry and number of units. In both scenarios, the height of the transition zone was adjusted to be between 1/4 and 1/5 of the opening (3~3.5 m), set at 70 cm. For the material, 30×30×5 cm bricks were employed, a size frequently found in historical buildings and representing an average among various types. 3 cm of mortar thickness was applied between the bricks. Considering the diagonal length of the brick material, the base of each triangular prism was established at 40-45 cm.

To unveil the geometry of the belt of Turkish triangles before construction, the top level of the wall and the initial level of the dome are determined using timber scaffolding. The scaffolding serves a dual purpose by adjusting the beginning of the transition zone and establishing the centre of the radius and the springing level of the dome. Following this, a border consisting of two or three rows of bricks projecting towards the space between the wall and the triangular units is constructed to provide a smooth surface for the transition zone. Subsequently, the fundamental geometric contours of the triangular units -such as the vertex, base, and edge- can be easily established between these horizontal levels by creating guidelines with simple marking tools like rope and nails (Table 5b).

As the construction of the belt of Turkish triangles primarily involves the symmetrical repetition of quarters, it is sufficient for the builder to organize the triangular or prismatic units based on the quarters of the space, with the corner part remaining in the middle. The fundamental contours of the triangular units, including corners and edges, could be determined by dividing the border at the lower part of the transition zone and the scaffolding passing through the upper part of the transition zone into four, eight, or more parts, depending on the geometric form of the belt of Turkish triangles. Guide ropes can then be drawn between these divisions, and the triangular or prismatic units, comprising rows of bricks, can be constructed following these guidelines (Table 5b).

In the plane triangular type, two different corner solutions exist. In the case of an upward-facing plane triangle (base at

Table 5. Construction technique of the belt of Turkish triangles via 3D models (Designs by Author); (a) two main geometric types and different corner solutions, (b) establishing scaffolding and the geometry of the triangular units, (c) beginning of construction with triangular units with their bases on the wall, (d) knitting triangular units opposite to the triangular spaces in between, (e) knitting straight and inverted triangular units all together to the end and (f) core of the transition zone

the top) at the corners (Table 5(1)), the construction commences with triangular units whose bases rest on both sides of the corner part and extend along the transition zone up to a certain level (Table 5(1.1), 5(1.2)). Consequently, the triangular units with bases on the walls act as moulds for the triangular units in between, with their tips touching the wall and bases facing upwards, providing support to keep them standing (Table 5(1.3)). When constructing the triangle facing upwards in the corner, a full brick is initially placed in the corner of the wall, forming the peak of the triangle in the corner. Subsequently, the shapes of the bricks are broken or cut and adjusted accordingly, taking the triangles on both sides of the corner as a reference and ensuring no gaps on the inner surface of the wall. As the triangular units facing upwards reach the level of the mould triangles, the construction of all triangular units is carried out simultaneously until the transition zone is completed (Table 5(1.4), 5(1.5)).

If there are two downward-facing plane triangular units in the corner (Table 5(2)), the positioning of the units is simpler compared to the first application, requiring less brick shaping. When the horizontal rows of bricks forming these two triangular units in the corner are constructed using a corbelling system following the reference lines, the dome skirt is already reached (Table 5(2.1), 5(2.2)). The crucial aspect here is to fill the corner part, which is not visible from the front but remains empty inside, by perfectly completing the remaining space with full bricks using a corbelling system. After knitting the other downward-facing triangles in a similar manner, it is time to knit the upward-facing triangles (Table 5(2.3)). It is observed that those closest to the corners undergo the most folding to the right and left. This change in angle or direction on the surface can be achieved by removing excess triangle pieces from the front parts of the brick material depending on the position of the triangles (Table 5(2.3), 5(2.4), 5(2.5)).

In the case of the belt of Turkish triangles, featuring an upward-facing triangular prism in the corner region (Table 5(3)), the construction process follows a sequence akin to that of the triangular planes. However, a notable distinction emerges: in positioning the endpoints of the diamond shapes formed by the surfaces of two adjacent triangular prisms on the wall, it becomes imperative to initially construct the bases of the downward-facing triangular prisms (Table 5(3), 5(3.1)). These triangles, with their bases on the wall, are typically built with a 5-10 cm recess within the wall. This helps both adjust the centre of gravity of the triangular prisms during load transfer and helps the "badem"s stand out more clearly (Table 5(3.2), 5(3.3), 5(3.4)). In the corner region, the precise alignment of two bricks is essential, ensuring that their corners align with the guideline. The careful placement of bricks to form the "badem"s in the upper rows involves meticulous attention to ensure alignment with the reference lines and the absence of gaps between these shapes and the adjacent triangular units (Table 5(3.3), 5(3.4), 5(3.5)). As the "badem"s progress and reach their widest surface length, nearly horizontal in orientation, across one or two more rows, depending on the transition zone's height, the subsequent step involves crafting the plane triangular surfaces of the upward-facing triangular prisms. In these constructions, the spaces that appear between the diverging "badem"s signify the areas to be filled with these triangular units, completing the intricate geometry of the structure (Table 5(3.4)). This sequential process ensures a snug fit and cohesion between the various elements, enhancing the overall stability and aesthetics of the design.

Certainly, these sections, characterized by the mirrored symmetry of the triangular units leaning against the wall at the base, can be completed progressively until the transition zone's construction is finish (Table 5(3.4)). It is very important not to overlook that the bricks that make up the triangular units or "badem"s need to be cut or broken in order to fit into place. Additionally, joints, especially on the interior of the wall, should be overlapped as staggered as possible to ensure that each unit integrates with each other and with the core of the wall (Table 5(3.5)).

In the case of two downward-facing triangular prisms in the corner, a "badem" is positioned between the corner of the wall and the dome (Table 5(4)). Similar to the previous application, the construction begins with knitting triangular surfaces with their bases on the wall, accounting for the height of the transition zone and the "badem"s to be inserted in between (Table 5(4.1), 5(4.2)). The spaces between the triangular units are filled with "badem"s, guided by reference lines, making it considerably easier to elucidate the geometry of the "badem"s in the corner compared to the previous type (Table 5(4.3)). This ease arises because, when a full brick is positioned in the corner and the rows are elevated using the corbelling system, the "badem" naturally emerges (Table 5(4.3), 5(4.4), 5(4.5)). If the "badem" with flat surface are in the corner (Table 5(5)), the construction sequence remains similar to the previous one (Table 5(5.1), 5(5.2), 5(5.3)). The only distinction is that the straight edges of the bricks are laid at the corner using the corbelling system instead of the corners on the front (Table 5(5.4), 5(5.5)).

It's important to note that both the outer and inner layers of the wall or drum, consisting of the transition zone with the belt of Turkish triangles, are built together (Table 5(1.4), 5(2.4)). The outer part of the drum, taking the form of an octagon or polygon, is typically completed using the alternate wall technique, similar to the main walls, and the core section is filled with a mixture of rubble and mortar. The part that inclines the most inward at the corners is supported by a buttress on the outer surface of the drum.

It is necessary to underline some important points regarding the construction of prismatic units (Table 5(3), 5(4), 5(5)); the arrangement and forms of the bricks differ from the previous plane triangular applications. Here, the edge surfaces of the bricks are utilized to form the base surfaces of the prisms (Table 5(3.2), 5(4.2)), either against the wall or the dome, while the brick corners are employed to shape the other triangular surfaces in between them. Essentially, this process creates "badem"s by using the corner part of a full-size or smaller brick (Table 5(3.3), 5(4.3)). Consequently, two consecutive edges of the same brick form two folded triangular surfaces of the "badem" (Table 5(3.4), 5(4.4)). The inclination or projection of these "badem"s varies based on their position within the transition zone. Furthermore, the shapes of the bricks themselves also change, influenced by both the "badem" and the adjacent triangular units (Table 5(3.5), 5(4.5), 5(5.5)). It is important to highlight that the size of the brick utilized in the transition zone has a direct impact on the size of the resulting triangular prisms. This ensures that the longest horizontal length of the "badem" does not surpass the diagonal length of a full brick size. If this ratio isn't maintained, particularly in corners with the widest openings, issues may arise where the bricks forming the "badem"s don't effectively integrate with the core of the wall. This could lead to difficulties in properly closing the surfaces, causing the "badem"s to shift apart. Consequently, in the belt of Turkish triangles consisting of triangular prisms, the precise positioning of triangular units in close proximity to each other is crucial to avoid such complications and ensure structural integrity (Table 5(3.4), (3.5), (4.4), (4.5), (5.4), (5.5)).

The construction of the outer drum portion of the transition zone follows a consistent method. Together with the Turkish triangles, the outer wall shell of the transition zone is built simultaneously with an infill core composed of rubble and mortar. As a result, both the inner Turkish triangle zone-featuring the triangular units-and the outer wall or drum are structurally integrated in a rigid state (Figure 20).

CONCLUSION

The structures with the belt of Turkish triangles, which served as a popular transitional element from the Seljuk to the Classical Ottoman Period spanning the 12th to the 15th centuries, boast a history of nearly three centuries. When evaluating the literature on the belt of Turkish triangles, it becomes evident that existing studies predominantly concentrate on the two-dimensional formal properties of the triangular units constituting the belt of Turkish triangles. These studies partially touch upon materials and construction techniques.

In this particular study, an extensive examination of various examples of the belt of Turkish triangles from the Seljuk Period to the Ottoman Period was conducted. Unlike previous works, this research not only delves into the formal and geometric features of the belt of Turkish triangles but also, for the first time in the literature, categorizes and

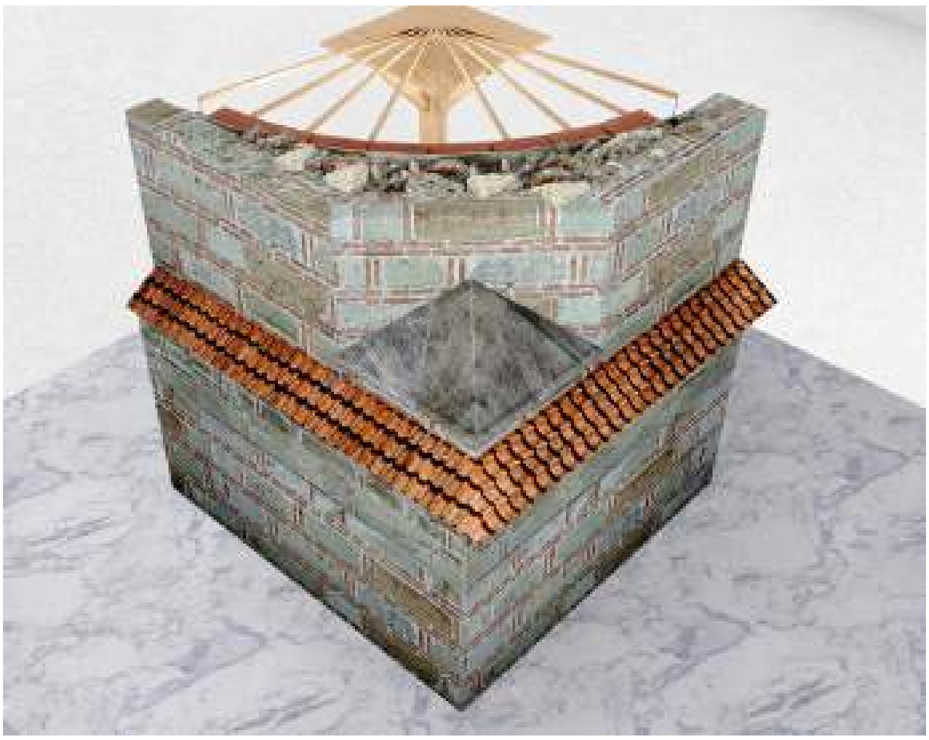


Figure 20. 3D Modelling of transition zone with the belt of Turkish triangles.

presents the ways the belt is utilized in the transition between different plan types and domed top covers. It further explores the relationships between the interior and exterior surfaces and analyses how the belt reflects on the facade, encompassing all possible variations.

Furthermore, the study explores in detail the materials and construction techniques employed in the belt of Turkish triangles, showcasing its diverse geometric shapes. This examination is based on data obtained from numerous field studies, coupled with insights from existing literature. The construction techniques of all geometric and formal types used in the belt of Turkish triangles are elucidated through the creation of three-dimensional models.

When evaluated in terms of form, despite the limited use of pendentives and squinches, the belt of Turkish triangles made a significant impact on its period with its flexible design that facilitated the transition from spaces with regular geometries, such as squares, rectangles, and polygons, to irregular geometries like trapezoids and ultimately to the dome. Additionally, the belt of Turkish triangles, which envelops the dome's drum like a horizontal band, has evolved over the centuries through trial and error processes into a visually rich array of forms, ranging from simple triangular surfaces to the prismatic and complex Turkish triangular belts known as "badem" and combined triangular prisms, as well as various combinations of these. Therefore, the flexible structural solutions and aesthetic contributions provided by the formal richness of the belt of Turkish triangles have played a significant role in its widespread preference in various building types, such as mosques, madrasas, baths, and tombs.

When evaluated in terms of materials, the transition zoneformed by the sequential arrangement of triangular or prismatic units facing upward and downward is primarily constructed using brick. In some cases, a hybrid technique is employed that integrates both brick and stone, while stone alone is rarely used, typically arranged using a stacking method. The brick can be utilized in standard sizes, such as whole, half, or quarter units, to reveal the shape of the triangular or prismatic units, or it can be used in irregular forms by breaking the edges to fit the designated placement. Since plaster is generally applied to the transition area, the full form of the units is revealed through thick joints, while precise craftsmanship is not necessary in shaping the brick material.

When evaluated in terms of construction techniques, the height of the transition area is adjusted in proportion to the dimensions of the space to ensure that the loads from the roof are evenly transferred to the walls. Subsequently, the organization of the units that form the transition area is determined by guide strings attached to wooden scaffolding, which define the finishing point of the wall and the starting line of the dome. While a more flexible adjustment is possible for the number or dimensions of units in simple triangular surfaces, in prismatic triangles, the number of units is directly related to the size of the bricks. Specifically, while the face surfaces of the bricks are used in simple triangular surfaces, in prismatic triangles, the corners of the bricks are utilized to achieve "badem"s or combined triangular prisms. Therefore, the widest part of the "badem" should not exceed the diagonal length of the whole brick.

The construction of the transition area begins at the corners, as the corner regions are more inclined and the triangular or prismatic units positioned side by side bend at more pronounced angles compared to the central units. Instead of constructing the transition area in pieces with corners and surfaces, once the corner sections reach a certain height, the neighbouring units are also raised to the same level, gradually completing the transition area. This allows triangular units that only touch the wall at their apex and expand upward to be supported by adjacent triangular units that are positioned in the opposite direction, ensuring that the transition area is completed securely. Additionally, any potential conflicts that may arise within the bricks of two neighbouring units can be easily resolved by cutting or breaking the bricks.

When the transition area is completed, a polygonal base is formed based on the number of units. To fill the gaps between the circular base of the dome and this polygonal base, a border consisting of an average of two to three rows is applied in between. This allows the dome base to be positioned perfectly on a complete circular plan.

In conclusion, the belt of Turkish triangles is a structural element that requires meticulous adjustments in its construction due to its various formal applications, in other words, it demands skilled craftsmanship. Although the use of the belt of Turkish triangles diminished after the 15^{th} century with the increasing importance of constructing spaces with relatively larger spans for structural reasons, it was utilized in countless buildings for an average of three centuries. The structures from the Seljuk, Beylik, and early Ottoman periods represent a significant portion of our cultural heritage, and it is essential to preserve them and pass them on to future generations. Unfortunately, some of these structures have faced neglect, resulting in damage or even collapse. When restoration becomes necessary, a meticulous analysis and understanding of the material, construction techniques, formal characteristics of the building and safeguarding their historical integrity for posterity are crucial.

For this reason, it is hoped that this study, revealing the formal/geometric features, material usage, and construction techniques of the belt of Turkish triangles, serves as a guide for restoration studies and as a pioneer for further research in this field.

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NOTES

[1]This study adopts the term *belt of Turkish triangles (Türk üçgeni kuşağı, in Turkish)* due to its generic descriptive capacity, which allows for a typologically inclusive discussion without being limited to a single geometric definition. Its presence in recent scholarly literature also supports its continued use. It should also be noted that numerous terminologies have been used to describe the belt of Turkish triangles both in Turkish and in English. Many of these terminologies are derived from the shape of the units comprising the belt.

In Turkish sources, it is referred to as "üçgenli kuşak" in studies of Seljuk architecture (Kuran, 1969; Batur, 1980). In works describing its architectural features, various other terms are used, such as "üçgen satıhlar" (Söylemezoğlu, 1955; Tansuğ, 1965), "dilimli kuşak", "baklavalı kuşak", "bademli üçgen kuşak", "göbekli baklavalı kuşak" and in Arabic, "müstevi alikalarla mürekkeb kuşak" and "müselles dilimli kuşak" (Ayverdi, 1957; Ayverdi, 1965). Other expressions include "prizmatik üçgenli kuşak", "düzlem üçgenlerden oluşan Türk üçgeni kuşağı", "Türk üçgen(ler)i", "üçgen badem kuşak", and "Türk üçgenleri kuşağı" (Acun, 1985; Kolay, 2017).

Additionally, geometric or symbolic terms such as "müselles-i kürevi" and "müselles-i dilim" are also found (Ayverdi, 1953), along with references to Arabic numerals seven (٧) and eight (٨), due to formal similarities (Uluengin et al., 2001).

In English-language sources, terms such as folded planes, prismatic surfaces, prismatic folded surface (Acland, 1972), belt of triangular planes (Kuran, 2012), and belt of Turkish triangles (Diri Akyıldız, 2018) have been used to describe this architectural feature.

[2]This situation can be determined when the following sources, which are extremely important for the history of architecture and construction technique of transition elements, are examined. See. Ousterhout, R. (1999). Master builders of Byzantium. Princeton University Press, pp. 201-204, Pope, A. U. (1967). A survey of Persian art; from prehistoric times to the present, Vol. II, Oxford University Press, pp. 525-539; Donald Wilber, D. (1969). *The architecture of Islamic Iran*. Greenwood Press, p. 42- 51, and Creswell, K. A. C. (1969). *Early Muslim architecture.* Vol. II, Oxford, pp. 450-463.

[3]The theses written in recent years on this subject can be examined, please see. Kula Say, S. (2007). Erken dönem Osmanlı hamamlarında eğrisel örtüye geçiş sistemleri (Publication No. 222016) [Unpublished Master dissertation, İstanbul Technical University], pp. 1-3; Şimşek, H. (2010). Erken Osmanlı mimarisinde kubbeye geçiş sistemlerinden Üçgenler Kuşağı (Publication No. 313918) [Unpublished Master dissertation, Yüzüncü Yıl University], pp. 31-36; Okçuoğlu, T. (1995). Anadolu Selçuklu mescitlerinde kubbeye geçiş alanının değerlendirilmesi (Publication No. 41668) [Unpublished Master dissertation, İstanbul University], pp. 13-14.

[4]Many international regulations on conservation3, such as the Venice Charter (1964), Charter on the Built Vernacular Heritage (1999), and the Nara Declaration of Authenticity, also underline that the originality, integrity and values of cultural assets should be preserved and transferred to future generations. For the Venice Charter, please see, ICOMOS. (1964). International Charter for the Conservation and Restoration of Monuments and Sites. https://www.icomos.org/images/DOCUMENTS/Charters/venice_e.pdf. For Charter on the Built Vernacular Heritage, please see, ICOMOS. (1999). Charter on the Built Vernacular Heritage. https://www.icomos.org/images/DOCUMENTS/Charters/vernacular_e.pdf. For the Nara Declaration of Authenticity, please see, ICOMOS. (1994). The Nara Document on Authenticity. https://www.icomos.org/en/charters-and-texts/179-articles-en-francais/ressources/charters-and-standards/386-the-nara-document-on-authenticity-1994.

[5]Mihrab is a recessed space in the wall of a mosque where the imam stands while leading prayers (Hasol, 2012; 322).

[6]Diamond shaped surfaces used between triangular shaped surfaces, used to enrich the belt of Turkish triangles are called "badem" or "baklava".

[7]The belt of Turkish triangles with combined triangular prisms refers to "göbekli Türk üçgeni" in Turkish. While explaining the usage of this type of the belt of Turkish triangles in the sources, the terminology of the "göbekli Türk üçgeni" is encountered. Please see, (Ayverdi, 1957; Ayverdi, 1965).

[8]The "halvet" is a single basin bathing cell in baths (Hasol, 2012; 197).

REFERENCES

AA. (n.d.a). *Beçin Antik Kenti'ndeki Yelli Camii 500 yıl sonra ibadete açılıyor [The Yelli Mosque in the ancient city of Beçin is reopening for worship after 500 years].* Retrieved November 26, 2024, from https://

www.trthaber.com/haber/kultur-sanat/becin-antik-kentindeki-yelli-camii-500-yil-sonra-ibadete-aciliyor-397240.html

AA. (n.d.b). *630 yıllık cami restore edildi [The 630-year-old mosque has been restored].* Retrieved January 18, 2025, from https://www.aa.com.tr/tr/kultur-sanat/630-yillik-cami-restore-edildi/608072

Acland, J. H. (1972). *Medieval structure: The Gothic vault*. University of Toronto Press.

Acun, H. (1985). Manisa'daki türbe mimarisi [The tomb architecture in Manisa]. *Belleten, 49*(195), 479–502. https://doi.org/10.37879/belleten.1985.479

Adam, J. P. (1994). *Roman building materials and technique* (A. Mathews, Trans.). Routledge.

Aslanapa, O. (2003). *Türk sanatı [Turkish Art]* (6th ed.). Remzi Kitabevi.

Atay, G., & Gül, Z. S. (2020, December 7–11). Clay pots of Ottoman architecture: Acoustics, structure, and ventilation. *Proceedings of Meetings on Acoustics, 42*(1), 1–12. https://doi.org/10.1121/2.0001387

Ayverdi, E. H. (1953). *Fatih devri mimarisi [Architecture of the Fatih period]*. İstanbul Matbaası.

Ayverdi, E. H. (1957). *Orhan Gazi devrinde mimari [Architecture in the time of Orhan Gazi]. Ankara Üniversitesi İlahiyat Fakültesi Yıllık Araştırmalar Dergisi, 1*(1), 115–197.

Ayverdi, E. H. (1965). *Bursa Orhangazi Camii ve Osmanlı Mimarisinin menşei meselesi [The issue of the origin of the Orhangazi Mosque and Ottoman Architecture in Bursa]. Vakıflar Dergisi, 6*(6), 69–84. https://isamveri.org/pdfdrg/D00143/1965_6/1965_6_AYVERDIEH1.pdf

Batur, A. (1980). *Osmanlı mimarisinde eğrisel örtüler ve geçiş öğeleri: Sorunlar ve biçimler [Curved coverings and transition elements in Ottoman architecture: Issues and forms]*. İstanbul.

Bayatlı, O. (1956). *Bergama tarihinde Türk İslam eserleri [Turkish Islamic monuments in the history of Pergamon]*. Anıl Matbaası.

Bilici, K. (2016a). *The heritage of Anatolian Seljuk Era, architecture* (Vol. 2). Selçuklu Belediyesi.

Bilici, K. (2016b). *The heritage of Anatolian Seljuk Era, architecture* (Vol. 3). Selçuklu Belediyesi.

Boran, A. (2001). *Anadolu'daki içkale cami ve mescidleri [The inner castle mosques and mescids in Anatolia]. Türk Tarih Kurumu Basımevi.*

Creswell, K. A. C. (1969). *Early Muslim architecture* (Vol. II). Oxford.

Çağlar, B., Bor, H. O., & Vural, S. (2021, June 28–29). Türk Üçgeninin parametrik modellenmesi ve robotik üzerine bir yöntem [A method on parametric modeling of the Turkish Triangle and robotics]. In G. Çağdaş, M. Özkar, L. F. Gül, S. Alaçam, E. Gürer, S. Yazıcı, B. Delikanlı, Ö. Çavuş, S. Altun, & G. Kırdar (Eds.), *Mimarlıkta Sayısal Tasarım XV. Ulusal Sempozyumu Bildiri Kitabı* [Proceedings of the 15th National Symposium on Digital Design in Architecture] (pp. 159–169). İstanbul Teknik Üniversitesi Yayınları.

Çolak, S. R. (2025). Mihrabı Çalınan; *Beyhekim Camii [The mihrab of Beyhekim Mosque that was stolen].* Retrieved Jan 9, 2025, from: https://www.memleket.com.tr/mihrabi-calinan-beyhekim-camii-1044278h.htm

Diez, E. (1946). *Türk sanatı [Turkish art]* (O. Aslanapa, Trans.). İstanbul Üniversitesi Edebiyat Fakültesi Yayınları.

Diri Akyıldız, F. (2018). *Construction techniques of the 14th-16th century Ottoman baths in Edirne* (Publication No. 503042) [Unpublished doctoral dissertation]. Middle East Technical University.

Gabriel, A. L. (1934). *Monuments Turks D' Anatolie Amasya-Tokat-Sivas [Turkish Monuments of Anatolia: Amasya-Tokat-Sivas]*. Boccard.

Hasol, D. (1995). *Ansiklopedik mimarlık sözlüğü [Encyclopedic dictionary of architecture]* (6th ed.). YEM Yayın.

Hasol, D. (2012). *Ansiklopedik mimarlık sözlüğü [Encyclopedic dictionary of architecture]* (12th ed.). YEM Yayın.

ICOMOS. (1964). *International Charter for the Conservation and Restoration of Monuments and Sites*. Retrieved Jan 9, 2025, from https://www.icomos.org/images/DOCUMENTS/Charters/venice_e.pdf

ICOMOS. (1994). *The Nara Document on Authenticity*. Retrieved Jan 9, 2025, from https://www.icomos.org/en/charters-and-texts/179-articles-en-francais/ressources/charters-and-standards/386-the-nara-document-on-authenticity-1994

ICOMOS. (1999). *Charter on the Built Vernacular Heritage.* Retrieved Jan 9, 2025, from https://www.icomos.org/images/DOCUMENTS/Charters/vernacular_e.pdf

İrteş, M. S. (2021). Bursa Çelebi Mehmed (Yeşil) Camii kalemişleri [Calligraphy of the Çelebi Mehmed (Green) Mosque in Bursa]. *Lale Kültür Sanat ve Medeniyet Dergisi, 3*, 72–83. https://dergipark.org.tr/tr/download/article-file/1509633

Kolay, İ. A. (2016, June 2–3). *Osmanlı Dönemi inşaat belgelerine göre anıtsal yapılarda örtü ve duvar sistemleri [Roof and wall systems in monumental structures according to Ottoman period construction documents].* In *8. Ulusal Çatı & Cephe Sempozyumu Bildiriler Kitabı* [8th National Roof & Facade Symposium Proceedings] (pp. 211–219). Mimar Sinan Güzel Sanatlar Üniversitesi Mimarlık Fakültesi, B2B Medya Yayınları.

Kolay, İ. A. (2017). *Batı Anadolu 14.yy Beylikler mimarisinde yapım teknikleri [Construction techniques* *in the 14th-century principalities architecture of Western Anatolia] (2nd ed.)*. Atatürk Kültür Merkezi Başkanlığı.

Kuban, D. (1976). *Edirne'de bazı İkinci Murat Çağı hamamları mukarnas bezemeleri üzerine notlar: İsmail Hakkı Uzunçarşılı'ya armağan [Notes on muqarnas decorations in 2nd Murad era hamams in Edirne: A tribute to İsmail Hakkı Uzunçarşılı]*. Türk Tarih Kurumu Yayınları.

Kuban, D. (1998). *Mimarlık kavramları [Concepts of architecture] (5th ed.)*. YEM Yayın.

Kuban, D. (2007). *Osmanlı mimarisi [Ottoman architecture]*. YEM Yayın.

Kula Say, S. (2007). *Erken dönem Osmanlı hamamlarında eğrisel örtüye geçiş sistemleri [Transition systems to curved coverings in early Ottoman baths]* (Publication No. 222016) [Unpublished Master's dissertation]. İstanbul Technical University.

Kuran, A. (1969). *Anadolu medreseleri [Anatolian madrasas] (Vol. 1)*. Türk Tarih Kurumu Basımevi.

Kuran, A. (2012). *Architecture in Turkey from the Seljuks to Republic* (Ç. Kafesçioğlu, L. Thys Şenocak, & T. Kuran, Eds.). Türkiye İş Bankası Kültür Yayınları.

Kutlu, M. (2017). *XIV–XV. yüzyıllara ait Osmanlı camilerinde görülen tuğla-taş almaşıklığı üzerine gözlemler [Observations on the brick-stone combination seen in Ottoman mosques of the 14th–15th centuries]. Sanat Tarihi Dergisi, XXVI*(1), 131–153. https://doi.org/10.29135/std.295727

Okçuoğlu, T. (1995). *Anadolu Selçuklu mescitlerinde kubbeye geçiş alanının değerlendirilmesi [Evaluation of the transition area to the dome in Anatolian Seljuk mosques]* (Publication No. 41668) [Unpublished Master's dissertation]. İstanbul University.

Ousterhout, R. (1999). *Master builders of Byzantium*. Princeton University Press.

Önkal, H. (1996). *Anadolu Selçuklu türbeleri [Anatolian Seljuk tombs]*. Atatürk Kültür Merkezi Yayınları.

Özdural, A. (1996). On interlocking or corresponding figures and ornamental patterns of cubic equations. *Muqarnas, 13*(1), 191–211.

Peker, A., & Bilici, K. (2006). *Anadolu Selçukluları ve Beylikler Dönemi Uygarlığı [Anatolian Seljuk and Principality Period Civilization]. Kültür ve Turizm Bakanlığı.* https://doi.org/10.1163/22118993-90000364

Pope, A. U. (1967). *A survey of Persian art; from prehistoric times to the present* (Vol. II). Oxford University Press.

Reyhan, K., İpekoğlu, B., & Böke, H. (2013). Construction techniques of domes in some Ottoman baths. *Journal of Cultural Heritage, 14*(3), 35–40. https://doi.org/10.1016/j.culher.2012.11.019

Rice, T. T. (1961). *The Seljuks in Asia Minor*. Thames and Hudson.

Rosintal, J. (1912). *Pendentifs trampen und stalaktiten* [Pendentives, trumpets, and stalactites]. University of Michigan Library.

SALT Research. (n.d.a). *Ülgen Family, Hacı Özbek Mosque (Çarşı Masjid)*. Retrieved November 26, 2024, from https://archives.saltresearch.org/handle/123456789/81655

SALT Research. (n.d.b). *Ülgen Family, Bursa Muradiye Mosque*. Retrieved July 22, 2025, from https://archives.saltresearch.org/handle/123456789/81275

SALT Research. (n.d.c). *Çalıkoğlu Family, Yeşil Mosque in İznik*. Retrieved July 22, 2025, from https://archives.saltresearch.org/handle/123456789/6760

SALT Research. *Ülgen Family. Acem Reis Mosque in Bursa*. Retrieved July 21, 2025, from https://archives.saltresearch.org/handle/123456789/68035

Söylemezoğlu, H. K. (1955). *İslam Dini İlk Camiler ve Osmanlı Camileri [The first mosques of Islam and Ottoman mosques]*. Pulhan Matbaası.

Şaşmaz, E. (2025, January 10). Parmaklı Mescit-Bergama fotoğraf galerisi *[Parmaklı Mescit-Bergama photo gallery]*. https://www.erolsasmaz.com/?oku=516

Şenalp, H. S., & Binan, C. Ş. (2024). Transformation of transitional elements with muqarnas from early Ottoman Period to Classical Ottoman Period. *Iconarp International Journal of Architecture and Planning, 12*(1), 463–503. https://doi.org/10.15320/ICONARP.2024.292

Şimşek, H. (2010). *Erken Osmanlı mimarisinde kubbeye geçiş sistemlerinden Üçgenler Kuşağı [Triangular Bands as dome transition systems in early Ottoman architecture]* (Publication No. 313918) [Unpublished Master's dissertation, Yüzüncü Yıl University]. Van.

Tanman, M. B. (1991). Ayas Ağa Külliyesi. In *TDV İslam Ansiklopedisi* (pp. 201–202), Vol. 4, İstanbul. https://islamansiklopedisi.org.tr/ayas-aga-kulliyesi

Tansuğ, S. (1965). *18. yüzyılda İstanbul çeşmeleri ve Ayasofya şadırvanı [Fountains in Istanbul in the 18th century and the fountain of Hagia Sophia]. Vakıflar Dergisi, 6*(6), 93–101.

Tunay, M. (1984). *Türkiye'de Bizans mimarisinde taş ve tuğla duvar tekniğine göre tarihlendirme [Dating the wall technique of stone and brick in Byzantine architecture in Turkey]* (Publication No. 123241) [Unpublished Master's dissertation]. İstanbul University.

Tuncer, O. C. (1984). Rönesans ve Klasik Osmanlı Dönemi dini yapılarda kubbenin amaç ve uygulanış açısından karşılaştırılması [A comparison of the aims and applications of domes in Renaissance and Classical Ottoman religious buildings]. *Vakıflar Dergisi, 18*, 125–140.

Turan, M. (1993). Domes and supports: Structural vulnerability of masonry shells. In C. A. Brebbia & R. J. B.

Frewer (Eds.), *Structural repair and maintenance of historic buildings III* (pp. 339–346). Computational Mechanics Publications.

Türkiye Kültür Portalı. (n.d.). *Muradiye Camii [Muradiye Mosque]*. Retrieved July 21, 2025, from https://www.kulturportali.gov.tr/turkiye/bursa/gezilecekyer/muradiye-camii

Uluengin, F., Uluengin, B., & Uluengin, M. B. (2001). *Osmanlı anıt mimarisinde klasik yapı detayları [Classical architectural details in Ottoman monumental architecture]*. YEM Yayın.

Ünsal, B. (1959). *Turkish Islamic architecture in Seljuk and Ottoman times 1071–1923*. Portland Press.

Wilber, D. (1969). *The architecture of Islamic Iran*. Greenwood Press.

Xodjoyeva, S. (2019, November). Bursa Yeşil Cami ve Yeşil Türbe çinileri [Tiles of the Green Mosque and Green Tomb in Bursa]. *Şehrengiz*, Chapter 2, 38–45.

Yarar, S. (2020). Amasya Kumacık Hamamı'nın ilk inşasındaki planına dair bir değerlendirme [An evaluation of the original plan of the Kumacık Bath in Amasya]. *Vakıflar Dergisi, 54*, 185–200. https://doi.org/10.16971/vakiflar.687583

Yavuz, A. T. (2002). Anadolu Selçuklu mimarisinin yapı özellikleri [Structural features of Anatolian Seljuk architecture]. In D. Kuban (Ed.), *Selçuklu çağında Anadolu sanatı* [Anatolian Art in the Seljuk Era] (p. 286). Yapı Kredi Yayınları.

Yıldız, V. (2025, January 16). *Prof. Dr. Kadir Pektaş tells about Yelli Mosque*. Retrieved Jan 9, 2025, from: https://habermilas.com/video/6999443/prof-dr-kadir-pektas-yelli-camini-anlatiyor

Yurt Haberleri. (n.d.). *The 600-year-old Yelli Mosque in the ancient city of Beçin is ready for worship [Beçin Antik Kenti'ndeki 600 yıllık Yelli Camii ibadete hazır]*. Retrieved January 18, 2025, from https://www.milatgazetesi.com/haber/becin

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Article

Exploring women's roles in urban sustainability: A study of gender equality initiatives in Antalya, Türkiye

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ABSTRACT

The 21st century is a period marked by challenges such as land degradation, resource scarcity, wars, crises, earthquakes, migrations and social and spatial inequalities, all of which disproportionately affect disadvantaged groups, including women. These challenges underscore the critical role of local governments in addressing gender equality within the framework of urban sustainability. This study examines the position of women in urban sustainability through the lens of Sustainable Development Goal 5 (SDG 5), which focuses on gender equality, by analyzing the approaches and actions of Antalya Metropolitan Municipality over a 10-year period (2014–2023). Using systematic review and comparative analysis methods with MAXQDA, the study evaluates the municipality's activity reports to assess how women are addressed in the social, physical/environmental, and economic dimensions of urban sustainability. The findings reveal that while significant progress has been made in addressing women's social needs, there is a lack of consistency and integration across the physical and economic dimensions. This imbalance highlights the need for a more holistic and interconnected approach to urban sustainability that empowers women as active participants in shaping the city. The study emphasizes the importance of bridging gaps between policy and practice, ensuring consistent implementation of gender-sensitive initiatives, and expanding efforts to address systemic inequalities in urban planning and governance. By adopting a more inclusive and integrated strategy, local governments can create equitable and sustainable urban environments where women play a central role in driving change. This research contributes to the growing body of literature on gender equality in urban sustainability and provides a framework for local governments to critically assess and improve their efforts in achieving SDG 5.

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INTRODUCTION

The pursuit of sustainable development is one of the most pressing challenges of the 21st century, encompassing a broad spectrum of economic, social, and physical/environmental objectives. The United Nations' Sustainable Development Goals (SDGs) provide a comprehensive framework, among which SDG 5—achieving gender equality and empowering all women and girls—is recognized as both a fundamental human right and a foundation for building peaceful, prosperous, and sustainable societies (Blanco & Mazmanian, 2014; Esquivel & Sweetman, 2016).

The relationship between gender equality and sustainable development is intricate and multifaceted. Gender inequalities—such as women's limited access to resources, decision-making, and safe urban environments—can hinder sustainable practices, whereas women's perspectives and leadership enhance inclusivity and resilience. Their involvement in environmental management, community leadership, and policy-making can lead to more inclusive and effective solutions (Ak & Braida, 2015; Ragheb, El-Wahab, & Ragheb, 2022; Lopez & Castro, 2020; Ataöv & Eraydin, 2011).

Urban areas, where the majority of the global population resides, are at the center of both sustainability challenges and gender inequalities. These inequalities are often expressed spatially through unequal access to housing, transport, safe public space, and social infrastructure. In this context, women's participation in urban planning and design becomes essential for building equitable cities. Feminist urban theorists have emphasized that planning processes are not neutral but often reflect and reproduce gendered power dynamics in space (Beebeejaun, 2009; Sandercock & Forsyth, 1992). Gender-sensitive planning can challenge these dynamics by promoting spatial justice, ensuring that all individuals, regardless of gender, have access to safe, inclusive, and empowering environments. This includes the design of public transport systems, housing policies, neighborhood services, and safety measures that reflect women's lived realities (Greed, 1994; Fainstein & Servon, 2005). By linking gender equality directly to urban planning, it becomes clear that spatial decisions shape women's mobility, caregiving roles, economic participation, and overall access to the city. Gender-responsive planning is thus both a theoretical and practical contribution to the discipline.

The role of women in urban settings is therefore particularly crucial, as they often bear the brunt of socio-spatial inequalities while also being key agents of change (Efe Güney, Tezcan, & Ağın, 2020). Women's participation in planning, governance, and community initiatives can drive progress towards more sustainable and equitable cities (Escalante & Valdivia, 2015; Chao, Gallego, Lopez-Chao, & Alvarellos, 2020; Hainard & Verschuur, 2001).

Local governments play a pivotal role in implementing sustainable development policies. Their proximity to communities allows them to tailor spatial strategies to the specific needs of different social groups, making them key actors in promoting sustainability (Hawkins & Wang, 2012; Brugmann, 1996). Unlike national governments, which often deal with broad policy frameworks and long-term strategies (Ala & Aydın, 2025), local governments can respond more swiftly and effectively to immediate challenges and opportunities within their jurisdictions. They can engage directly with residents, gather on-the-ground insights, and foster participatory decision-making processes that ensure diverse voices are heard.

Local governments also have the unique ability to integrate sustainability into various aspects of urban management, from transportation (Shiau & Liu, 2013) and housing (Norris & Hayden, 2018) to waste management (Joseph, 2006) and public health (Rantala, Bortz, & Armada, 2014). By adopting holistic and inclusive approaches, they can create synergies between different policy areas, leading to more comprehensive and effective solutions. For instance, promoting green infrastructure not only addresses environmental concerns but also enhances social well-being and economic resilience. Meanwhile, women's increasing participation in paid employment has transformed public place usage, creating a growing need for safe, accessible, and gender-sensitive urban environments, particularly in transportation, childcare facilities, and workplaces (Cetin & Turkun, 2022). These shifts underscore the urgency of developing integrated planning approaches that respond to the evolving patterns of mobility, caregiving, and labor force participation.

Promoting gender equality in urban planning is therefore not only a matter of justice but a prerequisite for building more sustainable and inclusive cities (Cetin & Turkun, 2022; Hainard & Verschuur, 2001). Local governments, as key decision-makers in shaping land use, public infrastructure, transportation systems, and social services, play a central role in realizing this vision.

Antalya, Türkiye's fifth-largest metropolitan city, offers a critical case for examining how local governments integrate gender-sensitive approaches within urban sustainability policies. With its diverse population and dynamic urban environment, Antalya faces a range of sustainability challenges that require innovative and context-specific solutions. This study analyzes the approaches and actions of the Antalya Metropolitan Municipality over a 10-year period (2014-2023), to assess how women have been addressed across the social, physical/environmental, and economic dimensions of urban sustainability. Using systematic review and comparative analysis methods, the research identifies policy gaps and inconsistencies, offering insights into the effectiveness of local government initiatives in promoting gender equality and sustainable development.

The findings reveal that while significant progress has been made in addressing women's social needs, there are notable gaps in the physical and economic dimensions, pointing to the need for a more integrated and consistent approach. By identifying policy gaps, inconsistencies, and fluctuations in gender-sensitive initiatives, this research emphasizes the importance of adopting a holistic strategy that bridges the social, physical, and economic dimensions of sustainability. Such an approach is essential for empowering women as active participants in shaping the city and achieving the broader goals of urban sustainability.

Beyond the empirical contribution, this study offers a framework for other cities to critically evaluate and strengthen their gender-focused urban policies, delivering valuable lessons for policymakers, urban planners, and community leaders. By systematically mapping municipal actions to SDG 5 sub-goals, the study provides a longitudinal and multidimensional assessment of gender mainstreaming at the local level. This framework enhances opportunities for comparative research and supports more strategic policymaking in urban sustainability and gender equality.

LITERATURE REVIEW

The 21st century presents a multiple challenges to urban environments, including mass migrations, increasing urbanization, and digitalization, as well as ecological constraints caused by climate change, such as rising sea levels, heat stress, drought, and water insecurity, as well as extreme rainfall (Horelli, 2017; Chapman, Watson, Salazar, Thatcher, & McAlpine, 2017). These complexities transform cities into dynamic environments where traditional planning and development approaches often fall short. Environmental harm, economic instability, and social inequalities threaten the viability of urban areas and the well-being of their populations. In response to these challenges, the literature highlights key urban planning concepts such as resilience, adaptation, equity, inclusivity, governance, integration, and strategic planning (Holling, 1973; Walker, Holling, Carpenter, & Kinzig, 2004; Fainstein, 2014). Collectively, these concepts emphasize that urban sustainability requires balancing social, environmental, and economic needs while ensuring fairness in the governance of scarce resources.

A critical aspect of this balance is addressing gender-based vulnerabilities. Acknowledging the varying capacities for adaptation among different groups is essential to managing resilience fairly and effectively (Reckien, et al., 2017). When women are excluded from urban resources and decision-making, inequalities deepen and inclusive development is blocked (Aina, 2011). In contrast, incorporating gender considerations into planning processes enables cities to tailor strategies more effectively, fostering environments where all residents can thrive (Escalante & Valdivia, 2015). As Beall (1996) emphasizes, gender equality is not only a matter of social justice but a foundation for sustainable growth. Urban systems are inherently multidimensional socio-ecological infrastructures (Solomon & Islam, 2021); integrating inclusivity and equality into their governance is crucial for both immediate functionality and long-term resilience.

Despite this recognition, the literature reveals a persistent gap between acknowledging gender equality and embedding it into planning practice. Gender dimensions are often overlooked or superficially addressed, resulting in planning processes that reinforce, rather than dismantle, inequalities (Beebeejaun, 2009; Rakodi, 1991; Sandercock & Forsyth, 1992; Greed, 1994). These omissions undermine social cohesion, environmental resilience, and economic vitality, challenging cities' long-term sustainability. By contrast, gender-sensitive planning emphasizes everyday lived experiences and enables more responsive and inclusive outcomes (Horelli, 2017).

Within this debate, the Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 provide a global framework for linking gender equality to sustainable development. SDG 5 specifically aims to empower women and girls and eliminate discrimination (United Nations, 2015; United Nations, 2020). It is closely connected with other goals, including governance, human rights, environmental sustainability, and poverty reduction (Leach, Mehta, & Prabhakaran, 2015; Kim, 2017; Esquivel & Sweetman, 2016). For urban planning, this underscores the importance of assessing women's participation across social, physical, and economic dimensions of city life as part of a holistic approach to inclusive development.

Recent scholarship on gender-responsive planning has coalesced around four main themes: participatory governance, gender mainstreaming in policy, gender-sensitive design interventions, and technology-enabled safety and inclusion (Gudekli, Dogan, Dogan, & Gudekli, 2023). A variety of methods advance this agenda, including bibliometric analyses to identify thematic gaps (Gudekli, Dogan, Dogan, & Gudekli, 2023), qualitative studies capturing women's lived experiences (Rampaul & Magidimisha-Chipungu, 2022), feminist spatial theory to interrogate gendered power and fear in urban space (Datta, 2021), and mixed-methods neighborhood studies examining how built environments shape gendered behaviors (Ghani, Rachele, Loh, Washington, & Turrell, 2019). Together, these approaches illustrate the multidimensionality of gender-responsive planning and the need for context-specific studies that link theory to practice.

Yet, important gaps remain. While the importance of gender equality is widely acknowledged (Greed, 1994; Fainstein & Servon, 2005), empirical studies that examine how local governments implement gender-focused policies in practice are limited. Many studies prioritize theoretical over concrete evaluation of policy implementation, and intersectional analyses remain scarce. This leaves unanswered questions about the effectiveness of gender-focused policies and their impact on everyday urban life. Local governments are uniquely positioned to address these gaps, given their proximity to residents and ability to implement policies at neighborhood scale (Brugmann, 1996; Hawkins & Wang, 2012). However, the mechanisms through which they mainstream gender into planning processes are not well understood.

Evidence also remains uneven across regions. Bibliometric reviews show that most studies are concentrated in a few countries and disciplines, limiting broader policy relevance (Gudekli, Dogan, Dogan, & Gudekli, 2023). In Türkiye, research has primarily focused on women's representation in local governments, gender-focused policies, women-friendly cities (Yucel & Kutlar, 2020; Korkmaz, 2023; United Nations , 2006). Additionally, there is a study evaluating gender equality practices within the framework of SDG 5 and in various businesses (Akdogan & Doğan, 2023). However, research analyzing municipal goals, strategies, and actions towards SDG 5 remain scarce. Internationally, similar patterns are observed: most studies focus on representation and service provision (Pini & Mcdonald, 2011; Everett, 2008) or broader SDG localization processes (Reddy, 2016; Mutiarani, Siswantoro, & Ntim, 2020; Guha & Chakrabarti, 2019; Perry, Diprose, Buck, & Simon, 2021), but systematic evaluations of gender-sensitive planning at the local level remains as a gap in the literature.

The urgency of addressing these gaps is heightened by external shocks (resource scarcity, wars, economic crises, earthquakes, and migration) faced in the 21st century that deepen socio-spatial inequalities and disproportionately affect women. Recognizing the different roles of each social group in shaping urban life is therefore essential for developing effective planning strategies.

All in all, this study examines how women's roles are addressed in Antalya's activity reports (2014-2023), focusing on social, physical/environmental, and economic dimensions of sustainable development. It analyzes the frequency and scope of women's issues in these reports, specifically in relation to SDG 5.

METHODOLOGY

Research Design and Case Context

This study investigates the implementation of practices related to women within the framework of SDG 5, "Gender Equality,". The focus is on Antalya Metropolitan Municipality, Türkiye's fifth-largest metropolitan city, chosen for its dynamic urban context, socio-spatial diversity and evolving gender policy landscape. Antalya's urban character -shaped by tourism, high levels of internal and international migration, and socio-economic variability- makes it a compelling setting to examine how local governments address gender equality within broader sustainability agendas (Turkish Statistical Institute, 2023).

Unlike Istanbul and Ankara, which are more commonly examined in academic and policy literature, Antalya represents a mid-sized but rapidly growing metropolitan region that has remained relatively understudied. This gap presents an opportunity to explore how gender-sensitive strategies are developed and implemented in cities beyond the dominant policy centers. Antalya also shows relatively high rates of female labor force participation, particularly in the informal and service sectors (Turkish Statistical Institute, 2021), further underscoring its relevance as a case for examining women's role in urban sustainability.

In recent years, Antalya Metropolitan Municipality has initiated various gender-related actions, including support for women entrepreneurs, social service provision, and efforts to design inclusive urban spaces (Antalya Metropolitan Municipality, 2022). These actions reflect an increasing local policy interest in gender mainstreaming and contribute to the broader objective of aligning municipal governance with the targets of SDG 5.

By focusing on Antalya, this research responds to the identified gap in empirical studies that evaluate the local implementation of gender equality strategies across social, physical/environmental, and economic dimensions. The city's unique challenges and opportunities allow for the generation of insights that are not only context-specific but also transferable to other municipalities in Türkiye and comparable urban contexts internationally. The research covers a 10-year period (2014 to 2023) and aims to assess the extent to which local authorities have addressed women's needs and empowerment through urban sustainability practices.

Data Collection and Analysis

The primary data source for this study comprises all activity reports published between 2014 and 2023, retrieved from the official website of the Antalya Metropolitan Municipality.

To analyze how women and gender-related issues are addressed in local policy discourse, the study employs a mixed-methods approach combining systematic review and comparative analysis, supported by MAXQDA 2024. The analysis incorporates both quantitative and qualitative methods to assess the frequency, framing and thematic depth of gender-focused municipal initiatives.

The quantitative analysis involves tracking the occurrence of gender-related references across the reports, with a focus on three key dimensions -social, physical-environmental, and economic. This allows for the identification of patterns, fluctuations, and trends over the 10-year period, highlighting changes in municipal attention to gender-related issues.

Qualitatively, the study examines how women's issues are discussed, analyzing narratives, themes, and language.

Additionally, to deepen the qualitative dimension of the analysis, each identified initiative was mapped against the relevant sub-targets of SDG 5. This mapping was used to assess the degree to which municipal practices align with specific global gender equality goals and to provide a more interpretative evaluation of women's empowerment efforts. It explores focus areas like social, physical-environmental, and economic dimensions, assessing policy implications. This combined approach offers a nuanced view of women's roles in urban sustainability, highlighting areas of progress and persistent gaps in policy implementation.

Table 1 provides a detailed overview of the hierarchical structure of the codes and sub-codes employed in the systematic review with MAXQDA 2024, including their respective distribution percentages.

The terms “women” and “woman” were designated as the parent code, representing the overarching category. The sub-codes were established as the social, physical-environmental, and economic dimensions, reflecting specific aspects of the broader category.

Table 1 shows that the social dimension dominates gender-related initiatives, while physical-environmental and economic aspects remain secondary. This imbalance suggests that the municipality has primarily framed gender equality through social programs rather than embedding it systematically into spatial planning or economic empowerment.

FINDINGS

In alignment with study's aim and scope, the activity reports published by Antalya Metropolitan Municipality in Türkiye between 2014 and 2023 were analyzed using a systematic review method and the designated codes/sub-codes in the MAXQDA 2024 program.

Table 1 presents the distribution percentages of initiatives aimed at improving or developing gender equality across different codes and sub-codes in all reports.This significant emphasis on the social dimension suggests that local government policies towards women have prioritized social initiatives over physical-environmental and economic ones. The predominance of social initiatives indicates a focused effort by the Antalya Metropolitan Municipality to address gender equality through programs and services that directly impact women's social well-being. These initiatives include efforts to improve access to social services, enhance educational and training opportunities, and support cultural and community activities that empower women.

Table 1. Codes used in the systematic review and percentage of codes

Parent Code	Sub-Code	Number of Documents	Number of Code	Percentage of Codes
Women Woman	Social	10	167	63%
	Physical and Environmental	10	58	21.9%
	Economic	9	40	15.1%
Total		**10**	**265**	**100%**

The second quantitative analysis, detailed in Table 2, further explores the distribution of codes across all activity reports. According to the analysis performed with MAXQDA 2024, the social dimension consistently exceeds initiatives addressing the physical-environmental and economic dimensions, corroborating the findings in Table 1. This consistency across multiple years underscores a sustained commitment to social initiatives, suggesting that the municipality has maintained a stable focus on enhancing women's social conditions.

The data reveals that while there are fluctuations in the number of initiatives each year, the social dimension remains the most prominent, indicating its central role in the municipality's approach to gender equality. This persistent focus may be driven by the immediate and visible impact of social programs on community well-being, as well as the potential for these initiatives to foster greater social cohesion and inclusivity. However, the relatively lower emphasis on physical-environmental and economic dimensions suggests opportunities for the municipality to expand its efforts in these areas, potentially leading to more comprehensive and balanced gender equality strategies that address the multifaceted challenges women face in urban environments.

Table 2 illustrates the frequency of references to gender-related initiatives across three dimensions -social, physical-environmental, and economic- based on content coding of municipal activity reports. This frequency-based analysis complements the qualitative thematic interpretation presented later in Table 3, offering a clearer picture of shifts in emphasis over time. Table 2 highlights fluctuations in the municipality's focus across the ten-year period. The sharp decline in 2020 reflects the disruptive effect of the COVID-19 pandemic, whereas the resurgence in 2022 demonstrates renewed attention to social and economic programs. These shifts underline the sensitivity of gender initiatives to external crises and changing political priorities, and reveal the need for institutionalized policies to ensure long-term progress.

This fluctuation suggests shifts in priorities or external influences, such as the COVID-19 pandemic, which likely contributed to the reduction in social initiatives in 2020. Meanwhile, the physical-environmental and economic dimensions also show year-to-year variation throughout the 2014-2023 period, although they received comparatively less emphasis than the social domain. This lack of a systematic relationship highlights the dynamic nature of policy focus and resource allocation the ten-year period from

Table 2. Frequency of codes by year in activity reports

	Activity Reports									
Sub-Codes	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Social	14	16	21	19	19	14	7	18	24	15
Physical and Environmental	4	8	9	9	4	5	4	6	6	3
Economic	2	0	2	3	1	2	5	8	9	8

2014 to 2023.

In addition, a qualitative analysis of the activity reports published by Antalya Metropolitan Municipality between 2014 and 2023 was conducted, focusing on gender equality. This analysis aimed to explore how the local government has approached gender equality over the decade, examining shifts in focus at the urban scale and identifying the categories under which gender equality has been addressed within the social, physical-environmental, and economic dimensions. The findings of this qualitative analysis are detailed in Table 3, providing insights into the thematic areas and initiatives that have been prioritized by the municipality.

The qualitative analysis delves into the specific initiatives and programs implemented by the municipality, offering a nuanced understanding of how gender equality has been integrated into various aspects of urban governance. By categorizing the initiatives into social, physical-environmental, and economic dimensions, the analysis highlights the breadth and diversity of efforts undertaken to promote gender equality. In the social dimension, initiatives such as educational programs, health services, and cultural activities reflect a commitment to enhancing women's social well-being and empowerment.

The physical-environmental dimension includes urban planning and infrastructure projects that consider gender-specific needs, aiming to create safer and more accessible public spaces for women. Meanwhile, the economic dimension focuses on initiatives that support women's employment and economic independence, addressing barriers to participation in the workforce.

This comprehensive analysis not only underscores the municipality's strategic priorities but also reveals areas where further efforts are needed to achieve a balanced and integrated approach to gender equality. By examining the evolution of these initiatives over the ten-year period from 2014 to 2023, the study provides valuable insights into the successes and challenges faced by the local government in fostering an inclusive urban environment.

Importantly, the Table 3 aligns each initiative with specific sub-goals of SDG 5. This alignment offers a deeper understanding of how these actions contribute to global gender equality targets, moving the analysis beyond frequency-based coding and toward thematic interpretation.

Table 3, derived from Antalya Metropolitan Municipality's activity reports, categorizes gender equality and women's issues into three dimensions: social, physical-environmental, and economic. This table presents a comprehensive mapping of all identified initiatives in Antalya Metropolitan Municipality's activity reports (2014–2023) with the corresponding SDG 5 sub-targets. It demonstrates the extent to which each activity aligns with the global gender equality framework

In the 2014 report, the social dimension focused on women's health, social services, education, and cultural activities, alongside counseling and sports initiatives. The physical-environmental dimension expanded to include landscaping projects and the construction of buildings and facilities, reflecting a broader approach to creating gender-inclusive spaces. The economic dimension continued to support women's employment and career planning, reinforcing the importance of economic empowerment (Antalya Metropolitan Municipality, 2014).

By 2015, the social dimension included a wide range of activities, from sports and health initiatives to spatial arrangements and violence prevention. This year marked a notable absence of economic activities, suggesting a potential shift in focus or resource allocation. The physical-environmental dimension included building construction, landscaping, and urban planning, indicating ongoing efforts to integrate gender considerations into the city's infrastructure (Antalya Metropolitan Municipality, 2015).

The 2016 report highlighted a diverse array of social initiatives, including gender equality programs, sports, health projects, and cultural activities. The physical-environmental dimension was active with urban planning, landscaping, and renovation projects, while the economic dimension featured economic support and career planning for women, reflecting a balanced approach across all dimensions (Antalya Metropolitan Municipality, 2016).

In 2017, the social dimension continued to prioritize gender equality, social services, education, and health projects. The physical-environmental dimension focused on landscaping and building construction, while the economic dimension included career planning and socio-economic activities, indicating a sustained commitment to comprehensive gender equality efforts (Antalya Metropolitan Municipality, 2017).

The 2018 report listed social services, spatial arrangements, and cultural projects as key social initiatives. The physical-environmental dimension included building construction and landscaping, while the economic dimension focused on career planning, suggesting a targeted approach to enhancing women's professional opportunities (Antalya Metropolitan Municipality, 2018).

In 2019, the social dimension featured a broad range of activities, including social services, sports, and cultural projects. The physical-environmental dimension was active with building construction and renovation, while the economic dimension included women's employment and

Table 3. Categorization of gender-focused urban initiatives by Sub-Codes and SDG 5

		Activity Reports										
Sub-Codes	**Local Initiative**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**Related SDG 5 Target**
Social	**Women's health initiatives**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.6[1], 5.2
	Social services and housing support	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.4[2], 5.5[3]
	Education and training activities	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.1[4], 5.5
	Counseling center services	✓	✓	✓	✓	✓	✓	✓	✓	✓		5.2[5], 5.5
	Culture and arts projects	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.5
	Sports activities	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.5
	Domestic violence prevention	✓		✓	✓		✓	✓	✓	✓	✓	5.2
	Gender equality initiatives			✓			✓		✓	✓	✓	5.c[6], 5.1
	Spatial planning	✓	✓	✓	✓	✓	✓	✓	✓			5.c
	Security services						✓					5.2
Physical and Environmental	**Landscaping projects**	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.c
	Building and facility construction	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.c
	Urban planning initiatives		✓	✓								5.c, 5.5
	Renovation practices			✓	✓		✓	✓	✓	✓	✓	5.c
	Urban regulations						✓					5.c
	Space allocation						✓		✓	✓	✓	5.a[7], 5.c
Economic	**Women's employment**	✓					✓	✓	✓	✓	✓	5.a, 5.5
	Career planning for women	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	5.a, 5.5
	Economic support for women		✓	✓			✓	✓	✓	✓	✓	5.a
	Socio-economic activities for women									✓	✓	5.4, 5.a

[1]Ensure universal access to sexual and reproductive health and reproductive rights as agreed in accordance with international agreements.
[2]Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family.
[3]Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life.
[4]End all forms of discrimination against all women and girls everywhere.
[5]Eliminate all forms of violence against all women and girls in the public and private spheres, including trafficking and sexual and other types of exploitation.
[6]Adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels.
[7]Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources.

career planning, highlighting a continued emphasis on economic empowerment (Antalya Metropolitan Municipality, 2019).

By 2020, the report showed a limited number of applications across all dimensions, likely due to the impact of the COVID-19 pandemic. The social dimension included social services, education, and security services, reflecting a focus on essential support during challenging times. The physical-environmental dimension featured urban regulations and spatial allocation, while the economic dimension included economic support and career planning, indicating a strategic response to the pandemic's challenges (Antalya Metropolitan Municipality, 2020).

The 2021 report summarized social initiatives such as social services, education, cultural projects, and violence prevention. The physical-environmental dimension included landscaping and building construction, while the economic dimension covered women's employment and economic support, suggesting a return to broader gender equality efforts post-pandemic (Antalya Metropolitan Municipality, 2021).

The 2022 report's social dimension included social services, counseling, cultural projects, and sports activities. The physical-environmental dimension focused on renovation and building construction, while the economic dimension featured career planning, women's employment, and socio-economic activities, indicating a comprehensive approach to gender equality (Antalya Metropolitan Municipality, 2022).

For the final period of this study, the 2023 report's social dimension included social services, counseling, cultural projects, and sports activities, similar to the previous year. The physical-environmental dimension focused on renovation, landscape planning and building construction, while the economic dimension featured career planning, women's employment, and socio-economic activities, indicating a comprehensive approach to gender equality (Antalya Metropolitan Municipality, 2023).

Analyzing the 2014-2023 activity reports reveals that initiatives on gender equality and women's issues are grouped into three dimensions: social, physical-environmental, and economic. The social dimension is the most extensive, with nine categories focusing on women's empowerment. These include social services, housing support, education, cultural projects, women's health, counseling, sports, and efforts against violence. These categories align with the literature's focus on social equity and the inclusion of women in local governance. The physical-environmental dimension, covering six categories, integrates gender considerations into urban development through planning, construction, landscaping, renovations, spatial allocation, and regulations. This aligns with SDG 5's call for equitable urban spaces. The economic dimension, with four categories, promotes women's financial independence via employment, economic support, career planning, and socio-economic activities. These initiatives address the literature's emphasis on economic empowerment as key to gender equality. In 2016, the social dimension was fully addressed across all nine categories, marking a peak in efforts to enhance women's well-being. The physical-environmental dimension saw significant focus in 2016 and 2023, covering four of six categories. Meanwhile, the economic dimension achieved full coverage in 2022 and 2023, reflecting growing attention to women's financial empowerment.

Across the decade, "social services and housing support" and "educational and training activities" were consistently implemented in every report within the social dimension. This consistency underscores the municipality's sustained commitment to addressing fundamental social needs, as emphasized in the introduction. In contrast, no single category was recurrently applied across all periods in the physical-environmental and economic dimensions. Notably, "building and facility construction" was the most frequent activity within the physical-environmental dimension, reflecting ongoing efforts to create inclusive urban spaces. In the economic dimension, "career planning for women" was the most frequently addressed activity, aligning with the literature's emphasis on supporting women's professional growth. It was also observed that "security services" within the social dimension were implemented only once, specifically in 2020, likely in response to the heightened need for safety during the COVID-19 pandemic. Among the physical-environmental dimension, "spatial allocation" and "urban regulations" had the least number of applications, suggesting areas for potential growth in integrating gender considerations into urban planning. In the economic dimension, "socio-economic activities for women" was the category with the fewest applications, indicating a need for further development in supporting women's economic participation. Overall, the analysis reveals a dynamic and evolving approach to gender equality in Antalya, with varying emphasis across dimensions and years. This reflects both the challenges and opportunities in aligning local government initiatives with broader goals of urban sustainability and gender equity, as discussed in the literature review.

A thematic interpretation of these findings reveals that while social programs such as education, counseling, and domestic violence prevention were consistently implemented, their qualitative impact varied across years. For instance, the persistent inclusion of cultural and sports activities signals a broad-based approach to social inclusion, yet lacks an explicit empowerment lens unless tied to leadership or skills development. In contrast, the emergence of initiatives like women's entrepreneurship and economic support—especially after 2020—suggests a gradual shift toward fostering women's agency and financial independence, aligning more closely with SDG 5 sub-targets such as 5.a and 5.5. However, the irregular presence of these initiatives highlights the need for more stable and institutionalized mechanisms that go beyond service provision and actively address structural inequalities.

CONCLUSION AND DISCUSSION

This study analyzed the ten-year period from 2014 to 2023 of Antalya Metropolitan Municipality's activity reports, revealing an evolving approach to women's role in urban sustainability. While strong social initiatives show commitment, a more holistic strategy is needed. The emphasis on social programs alone cannot ensure comprehensive gender equality. The physical and economic dimensions, though addressed, lack consistency and depth, highlight gaps in policy implementation. In parallel, although the social dimension demonstrates consistency and commitment through repeated implementation of educational, cultural, and social support programs, its transformative impact appears limited. The recurring nature of these interventions suggests a service-delivery model that addresses immediate needs without fostering deeper structural change. Most initiatives focus on access and inclusion but fall short of embedding long-term empowerment mechanisms. As such, without strategic innovation or participatory reform, the social dimension risks becoming routine rather than revolutionary. Thus, although the social domain shows relative consistency in municipal gender initiatives, its potential to drive long-term empowerment remains underutilized-mirroring the gaps observed in the physical and economic dimensions and reinforcing the need for a more integrated and transformative gender equality agenda at the local level. To align with SDG 5 and achieve urban sustainability, the municipality must adopt a more integrated approach, including:

Strengthening the Interconnection: Developing initiatives that bridge the social, physical, and economic dimensions. For example, urban planning projects should not only consider women's safety but also their economic participation and access to essential services.

Consistent Implementation: Ensuring consistent application of gender-sensitive policies across all years, avoiding fluctuations driven by changing priorities or external factors such as pandemics.

Broadening the Scope: Expanding initiatives within the physical and economic dimensions. This includes promoting women's entrepreneurship, ensuring equal access to economic resources, and designing public spaces that cater to women's needs and encourage their full participation in urban life.

Data-Driven Evaluation: Implementing robust monitoring and evaluation mechanisms to assess the effectiveness of gender-focused initiatives and guide future policy decisions.

By addressing these key areas, Antalya can create an inclusive, sustainable urban environment with empowered women as agents of change. This study offers a valuable framework for Antalya and other municipalities to assess their efforts and continuously improve gender equality within urban sustainability.

This study's findings contribute to the growing body of literature emphasizing the crucial role of local governments in promoting gender equality within the framework of urban sustainability. The dominance of social initiatives in Antalya's approach aligns with global trends documented by scholars like Pini and McDonald (2011) and Everett (2008), who found that local governments often prioritize social services and programs aimed at improving women's immediate needs. This approach, while essential, underscores the need to move beyond addressing immediate needs and focus on systemic changes that empower women across all spheres of urban life. The observed fluctuation in the implementation of gender-sensitive initiatives across different years echoes the dynamic nature of local governance highlighted by Brugmann (1996) and Hawkins and Wang (2012). External factors, shifting political priorities, and resource constraints can all influence the continuity and effectiveness of local government policies. This highlights the need for robust institutional mechanisms that ensure sustained commitment to gender equality, regardless of external pressures such as wars, crises or pandemics.

Furthermore, the study's findings regarding the limited integration of gender considerations within the physical and economic dimensions resonate with the literature's critique of traditional urban planning approaches. In addition, the integration of SDG 5 sub-targets into the analysis—particularly through the Table 3—enables a more detailed assessment of how local initiatives align with specific dimensions of gender equality. The categorization reveals that while most social initiatives are consistent with targets such as SDG 5.2 (eliminating violence) and SDG 5.5 (ensuring full participation and leadership), there is significantly less alignment with targets like SDG 5.a (economic access to resources) and SDG 5.c (adoption of gender-sensitive policies). This suggests an imbalance in thematic implementation, with an overemphasis on social interventions at the expense of more systemic or policy-driven actions required for long-term gender empowerment. As pointed out by Beebeejaun (2009), Rakodi (1991), Sandercock and Forsyth (1992), and Greed (1994), urban planning has often overlooked the diverse needs and experiences of women, resulting in environments that perpetuate gender disparities. Antalya's experience underscores the need for a paradigm shift in urban planning, moving away from a gender-neutral approach towards one that actively incorporates women's perspectives and priorities in the design and management of cities.

The study's findings also contribute to the limited research on local governments' efforts towards achieving SDG 5 in

Türkiye. While studies like those by Yucel and Kutlar (2020) and Korkmaz (2023) have examined women's representation and gender-focused policies in Turkish local governance, this research provides a more nuanced understanding of how these policies translate into concrete actions across different dimensions of urban sustainability.

The analysis of local initiatives across dimensions reveals that while the municipality has made commendable strides in addressing women's immediate social needs, a deeper integration of empowerment-oriented goals—such as long-term economic autonomy, spatial justice, and participatory governance—remains limited. The alignment with SDG 5 sub-targets shows promise, particularly where local efforts move from reactive service delivery to proactive structural change. For example, initiatives mapped to SDG 5.5 (ensuring full participation and leadership) and SDG 5.a (equal access to economic resources) appear only in later years, indicating a shift in municipal focus that warrants further institutional reinforcement. The study thus illustrates not only what types of gender-focused actions are taken, but also how their depth and transformative potential vary, offering critical insight into the evolving role of local governments in gender mainstreaming.

In conclusion, this study underscores the need for a more integrated and comprehensive approach to women's position in the city. By moving beyond a siloed approach and embracing the interconnectedness of social, physical, and economic dimensions, Antalya Metropolitan Municipality can create a more equitable and sustainable urban environment for all. This requires not only a commitment to gender-sensitive policies but also a fundamental shift in planning paradigms and governance structures to ensure that women are equal partners in shaping the future of their city.

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REFERENCES

Aina, O. I. (2011, November). *Promoting gender equality for sustainable development*. Conference of Social Development and Gender Empowerment, Ekiti State, Adetiloye Hall, Trade Fair Complex, Ado–Ekiti.

Ak, H., & Braida, W. (2015). Sustainable municipal solid waste management decision making: Development and implementation of a single score sustainability index. *Management of Environmental Quality: An International Journal, 26*(6), 909–928. https://doi.org/10.1108/MEQ-03-2015-0028

Akdogan, N., & Doğan, D. U. (2023). Sürdürülebilir kalkınma hedeflerinden 5 no'lu toplumsal cinsiyet eşitliği hedefine ulaşmada Türkiye'de sürdürülebilirlik raporu düzenleyen işletmelerin 2020 ve 2021 yılı beyanlarının incelenmesi ve sonuçların değerlendirilmesi [Examination and evaluation of the statements of companies in Turkey that prepare sustainability reports in achieving goal 5 of sustainable development: Gender equality]. *Muhasebe Bilim Dünyası Dergisi, 25*, 219–240. https://doi.org/10.31460/mbdd.1213191

Ala, E., & Aydın, N. (2025). Türkiye'nin kalkınma planlarında halk sağlığı ve kentsel sağlığın ele alınışı [The treatment of public health and urban health in Turkey's development plans]. *Uluslararası İktisadi ve İdari İncelemeler Dergisi, 46*, 249–262. https://doi.org/10.18092/ulikidince.1513219

Antalya Metropolitan Municipality. (2014). *2014 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/Raporlar%2FFaaliyetRaporlari%2F2014_YILI_ABB_Faaliyet_Raporu.pdf

Antalya Metropolitan Municipality. (2015). *2015 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/Raporlar%2FFaaliyetRaporlari%2F2015_YILI_ABB_Faaliyet_Raporu.pdf

Antalya Metropolitan Municipality. (2016). *2016 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/Raporlar%2FFaaliyetRaporlari%2F2016_antalya_buyuksehir_belediyesi_faaliyet_raporu.pdf

Antalya Metropolitan Municipality. (2017). *2017 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/Raporlar%2FFaaliyetRaporlari%2F2017_Faaliyet_Raporu.pdf

Antalya Metropolitan Municipality. (2018). *2018 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/Raporlar%2FFaaliyetRaporlari%2FABB%202018%20Y%C4%B1l%C4%B1%20Faaliyet%20Raporu%20(Web%20Mini).pdf

Antalya Metropolitan Municipality. (2019). *2019 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/2019_yili_faaliyet_raporu.pdf

Antalya Metropolitan Municipality. (2020). *2020 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/2020-YILI-FAALIYET-RAPORU-WEB.pdf

Antalya Metropolitan Municipality. (2021). *2021 Activity Report*. Retrieved Jan 3, 2025, from https://www.

antalya.bel.tr/Content/UserFiles/Files/2021-YILI-FAALIYET-RAPORU-WEB.pdf

Antalya Metropolitan Municipality. (2022). *2022 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/ABB-2022-FAALiYET-RAPORU.pdf

Antalya Metropolitan Municipality. (2023). *2023 Activity Report*. Retrieved Jan 3, 2025, from https://www.antalya.bel.tr/Content/UserFiles/Files/ABB-2023-YILI-FAALIYET-RAPORU-(BILGI-ISLEM).pdf

Ataöv, A., & Eraydin, A. (2011). Different forms of governance: Responses of two metropolitan regions in Turkey to state restructuring. *Urban Affairs Review, 47*(1), 84–128. https://doi.org/10.1177/1078087410372608

Beall, J. (1996). Participation in the city: Where do women fit in? *Women and Urban Settlement, 4*(1), 9–16. https://doi.org/10.1080/741921946

Beebeejaun, Y. (2009). Making safer places: Gender and the right to the city. *Security Journal, 22*(3), 219–229. https://doi.org/10.1057/sj.2009.4

Blanco, H., & Mazmanian, D. A. (2014). The sustainable city: Introduction and overview. In D. A. Mazmanian, & H. Blanco (Eds.), *Elgar Companion to Sustainable Cities* (pp. 1–12). Edward Elgar Publishing. https://doi.org/10.4337/9780857939999.00005

Brugmann, J. (1996). Planning for sustainability at the local government level. *Environmental Impact Assessment Review, 16*(4–6), 363–379. https://doi.org/10.1016/S0195-9255(97)81658-7

Chao, A. L., Gallego, A. C., Lopez-Chao, V., & Alvarellos, A. (2020). Indicators framework for sustainable urban design. *Atmosphere, 11*(11), 1143. https://doi.org/10.3390/atmos11111143

Chapman, S., Watson, J. E., Salazar, A., Thatcher, M., & McAlpine, C. A. (2017). The impact of urbanization and climate change on urban temperatures: A systematic review. *Landscape Ecology, 32*, 1921–1935. https://doi.org/10.1007/s10980-017-0561-4

Cetin, R., & Turkun, A. (2022). The effects of women's joining in paid employment on public place usage: Sakarya Geyve case. *Megaron, 17*(1), 107–116. https://doi.org/10.14744/MEGARON.2022.08566

Datta, A. (2021). Gender, urban spaces and gendered resistances: Towards inclusive and fear-free cities in India. In *Reflections on 21st Century Human Habitats in India: Felicitation Volume in Honour of Professor MH Qureshi* (pp. 327–343). Springer Singapore. https://doi.org/10.1007/978-981-16-3100-9_13

Efe Güney, M., Tezcan, S., & Ağın, C. (2020). Planlamaya rağmen kentte var olabilmek: İzmir Konak'ta bir kadın dostu kent incelemesi [Being able to exist in the city despite planning: A study of a women-friendly city in Konak, İzmir]. *Planlama Dergisi*, 273–293. https://doi.org/10.14744/planlama.2020.08379

Escalante, S. O., & Valdivia, B. G. (2015). Planning from below: Using feminist participatory methods to increase women's participation in urban planning. *Gender & Development, 23*(1), 113–126. https://doi.org/10.1080/13552074.2015.1014206

Esquivel, V., & Sweetman, C. (2016). Gender and the sustainable development goals. *Gender & Development, 24*(1), 1–8. https://doi.org/10.1080/13552074.2016.1153318

Everett, J. (2008). *Women in local government in India*. Routledge.

Fainstein, S. S. (2014). The just city. *International Journal of Urban Sciences, 18*(1), 1–18. https://doi.org/10.1080/12265934.2013.834643

Fainstein, S. S., & Servon, L. J. (2005). *Gender and planning: A reader*. Rutgers University Press.

Ghani, F., Rachele, J. N., Loh, V. H., Washington, S., & Turrell, G. (2019). Do differences in social environments explain gender differences in recreational walking across neighbourhoods? *International Journal of Environmental Research and Public Health, 16*(11), 1980. https://doi.org/10.3390/ijerph16111980

Greed, C. H. (1994). *Women and planning: Creating gendered realities*. Routledge.

Gudekli, A., Dogan, M. E., Dogan, T. G., & Gudekli, D. (2023). Gender, sustainability, and urbanism: A systematic review of literature and cross-cluster analysis. *Sustainability, 15*(20), 14994. https://doi.org/10.3390/su152014994

Guha, J., & Chakrabarti, B. (2019). Achieving the Sustainable Development Goals (SDGs) through decentralisation and the role of local governments: A systematic review. *Commonwealth Journal of Local Governance, 22*, 1–21. https://doi.org/10.5130/cjlg.v0i22.6855

Hainard, F., & Verschuur, C. (2001). Filling the urban policy breach: Women's empowerment, grass-roots organizations, and urban governance. *International Political Science Review, 22*(1), 33–53. https://doi.org/10.1177/0192512101221003

Hawkins, C. V., & Wang, X. (2012). Sustainable development governance: Citizen participation and support networks in local sustainability initiatives. *Public Works Management & Policy, 17*(1), 7–29. https://doi.org/10.1177/1087724X11429045

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4*(1), 1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

Horelli, L. (2017). Engendering urban planning in different contexts – successes, constraints and consequences. *European Planning Studies, 25*(10), 1779–1796. https://doi.org/10.1080/09654313.2017.1339781

Joseph, K. (2006). Stakeholder participation for sustainable waste management. *Habitat International, 30*(4), 863–871. https://doi.org/10.1016/j.habitatint.2005.09.009

Kim, E. M. (2017). Gender and the sustainable development goals. *Global Social Policy, 17*(2), 239–244. https://doi.org/10.1177/1468018117703444

Korkmaz, H. (2023). Stratejik planlarda kadın: Belediyelerde bir inceleme [Women in strategic plans: A study of municipalities]. *Uluslararası İktisadi ve İdari İncelemeler Dergisi, 40*, 99–112. https://doi.org/10.18092/ulikidince.1292097

Leach, M., Mehta, L., & Prabhakaran, P. (2015). Sustainable development: A gendered pathways approach. In C. Johnson (Ed.), *Gender equality and sustainable development* (pp. 1–33). Routledge. https://doi.org/10.4324/9781315686455-8

Lopez, L. J., & Castro, A. I. (2020). Sustainability and resilience in smart city planning: A review. *Sustainability, 13*(1), 181. https://doi.org/10.3390/su13010181

Mutiarani, N. D., Siswantoro, D., & Ntim, C. G. (2020). The impact of local government characteristics on the accomplishment of Sustainable Development Goals (SDGs). *Cogent Business & Management, 7*(1), 1847751. https://doi.org/10.1080/23311975.2020.1847751

Norris, M., & Hayden, A. (2018). The future of council housing: An analysis of the financial sustainability of local authority-provided social housing. *Community Foundation of Ireland*.

Perry, B., Diprose, K., Buck, N. T., & Simon, D. (2021). Localizing the SDGs in England: Challenges and value propositions for local government. *Frontiers in Sustainable Cities, 3*, 746337. https://doi.org/10.3389/frsc.2021.746337

Pini, B., & Mcdonald, P. (2011). *Women and representation in local government*. In International case studies. Routledge.

Ragheb, G., El-Wahab, M. A., & Ragheb, R. A. (2022). Sustainable indicators framework for strategic urban development: A case study of Abu Teeg City in Assiut, Egypt. *International Journal of Sustainable Development & Planning, 17*(1). https://doi.org/10.18280/ijsdp.170109

Rakodi, C. (1991). Cities and people: Towards a gender-aware urban planning process? *Public Administration and Development, 11*(6), 541–559. https://doi.org/10.1002/pad.4230110603

Rampaul, K., & Magidimisha-Chipungu, H. (2022). Gender mainstreaming in the urban space to promote inclusive cities. *The Journal for Transdisciplinary Research in Southern Africa, 18*(1), 1163. https://doi.org/10.4102/td.v18i1.1163

Rantala, R., Bortz, M., & Armada, F. (2014). Intersectoral action: Local governments promoting health. *Health Promotion International, 29*(suppl_1), i92–i102. https://doi.org/10.1093/heapro/dau047

Reckien, D., Creutzig, F., Fernandez, B., Lwasa, S., Tovar-Restrepo, M., Mcevoy, D., & Satterthwaite, D. (2017). Climate change, equity and the Sustainable Development Goals: An urban perspective. *Environment & Urbanization, 29*(1), 159–182. https://doi.org/10.1177/0956247816677778

Reddy, P. S. (2016). Localising the Sustainable Development Goals (SDGs): The role of local government in context. *African Journal of Public Affairs, 9*(2), 1–15.

Sandercock, L., & Forsyth, A. (1992). A gender agenda: New directions for planning theory. *Journal of the American Planning Association, 58*(1), 49–59. https://doi.org/10.1080/01944369208975534

Shiau, T. A., & Liu, J. S. (2013). Developing an indicator system for local governments to evaluate transport sustainability strategies. *Ecological Indicators, 34*, 361–371. https://doi.org/10.1016/j.ecolind.2013.06.001

Solomon, D. S., & Islam, F. (2021). Examining the outcomes of urban adaptation interventions on gender equality using SDG 5. *Climate and Development, 13*(9), 830–841. https://doi.org/10.1080/17565529.2021.1939643

Turkish Statistical Institute. (2021). *Labor Force Statistics – Female Labor Force Participation Rate*. Retrieved Jun 20, 2025, from https://data.tuik.gov.tr/

Turkish Statistical Institute. (2023). *Address Based Population Registration System Results*. Retrieved Jun 20, 2025, from https://www.tuik.gov.tr/

United Nations. (2006). *United Nations Joint Programme on Women-Friendly Cities*. Retrieved Aug 13, 2024, from http://www.kadindostukentler.com/proje.php

United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. Retrieved Sep 1, 2022, from https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf?OpenElement

United Nations. (2020). *Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development*. Retrieved Mar 12, 2023, from https://unstats.un.org/sdgs/indicators/indicators-list/

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society, 9*(2), 5. https://doi.org/10.5751/ES-00650-090205

Yucel, I., & Kutlar, İ. (2020). Türkiye'de yerel yönetimlerin kadınlara yönelik hizmetlerinin toplumsal cinsiyet açısından incelenmesi [Examining the gender perspective of local government services for women in Turkey]. *Akdeniz Kadın Çalışmaları ve Toplumsal Cinsiyet Dergisi, 3*(1), 151–169. https://doi.org/10.33708/ktc.733045

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Article

Ecological landscape master plan according to landscape characterization in the case of Yalova Çınarcık District

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ABSTRACT

In the case of Çınarcık District, land suitability for settlement, agriculture, forest, and conservation was assessed based on potential, risk, and constraints. An 'Ecological Landscape Master Plan' was developed using GIS-supported Landscape Suitability Analysis (LANDEP) method. Character areas formed by landscape elements influence sustainable and conservation-oriented planning decisions. Natural structure components included 8 parameters, 57 criteria, and numerous sub-criteria. Analyses, synthesis, classification, and zoning were conducted to determine landscape structure. Landscape characterisation identified 7 regions and 92 sub-regions based on topography (19), soil (14), geology and geomorphology (21), hydrology (12), forest cover (9), protection areas (10), and risk factors (8). Approximately 83% of the area is prone to risks such as earthquakes, floods, landslides, and tsunamis. Of the earthquake risk zones, 5% of the area is currently inhabited, 1.8% is suitable with precautions, while 37.1% is unsuitable for settlement. About 4% of settlement areas lie on quaternary sedimentary ground, 2.3% on active fault lines, and 76% are located in coastal plains. The entire 8 km coastline is at tsunami risk. The central settlement sits on problematic young alluvial ground. Notably, 76% of buildings are over four storeys, and 320 are within the active fault line and 500 m protection zone, comprising 12% of all buildings. These risky zones must be classified as 'Exposure Areas,' with evacuation or demolition of vulnerable structures. Reconstruction should be based on microzonation and geological investigations. Notably, 70% of the area includes olive groves and agricultural and forest lands, which should be preserved to ensure sustainability.

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INTRODUCTION

According to the European Landscape Convention, countries are responsible for establishing ecological landscape master plans that prioritize cultural, environmental, agricultural, social and economic policies and planning to reveal the landscape structure and maintain its functions (European Landscape Convention, 2004).

Landscape planning aims to increase the value of landscapes, improve them and ensure integrity in determining future actions in the creation of new landscapes. The sustainability of the landscape's ecosystem services and its nature conservation functions is targeted throughout every stage of this process. The geology, geomorphology, topography, hydrology, soil structure, vegetation, climate structure and current land uses revealed by the natural structure constitute different landscape typologies in the land cover.

This pattern, shaped by unique, varied, and continuous elements within a landscape, defines its distinctive character. Landscape character types may differ across the world, yet remain homogeneous in terms of their intrinsic character. Landscape characters formed by natural components play a crucial role in guiding appropriate land use decisions, especially in determining suitable locations for settlements. Landscape Master Plans with an ecological approach are an effective planning tool in determining the appropriate conservation and utilization patterns for landscape structure at regional, country, city and local planning scales in ensuring nature conservation and sustainability (Uzun et al., 2012).

Çınarcık District, which had not been evaluated within this framework due to its richness of natural structure, diversity of landscape character areas and disaster risks due to its location, was selected as the research area.

MATERIAL AND METHOD

Material

In the literature review, documents such as institutional data, research reports, postgraduate theses, etc. were evaluated and field observations and controls were provided.

- Watershed, stream, wetland and flood boundaries from 1/25.000 scale Map General Directorate (HGM) digital data,
- Elevation, slope, orientation, geomorphological structure and units from 1/50.000 scale Digital Elevation Model (DEM) raster data,
- Soil structure, major soil groups, soil depth from 1/25.000 scale Ministry of Agriculture and Forestry digital soil map vector data format,
- Geology and geological formation from the General Directorate of Mineral Research and Exploration raster data format,
- Disaster and Emergency Directorate 2023 decisions on disaster prone areas,
- Geological structure, geological formation, earthquake zones, degree of erosion, fault lines, soil structure, flood boundaries from XML, PNG and JPEG formatted data from WEB map services of General Directorate of Geographical Information Systems,
- Current land uses were determined according to Land Monitoring Service (2018).

Method

Techniques applied in the process of creating basic base maps:

- Multiple layer operations, surface analysis, digitizing data with AutoCAD 2021 and ArcGIS Pro 3.2.2 software,
- Geographic Information System (GIS) supported analysis and synthesis,
- Obtaining land suitability maps with Optimal Suitability Analysis (LANDEP) method,
- Visual data were edited with Adobe Photoshop 2024 software.

Steps of the research:

1. Data content collection, database creation, scaling,
2. Revealing the landscape structure and attributes to support analysis and synthesis, and developing foundational base layers,
3. Thresholds such as protected and risk areas, protection statuses, restrictions according to natural components,
4. Determination of parameters, criteria and sub-criteria of landscape suitability analysis,
5. Analyzes and synthesizes according to land use suitability,
6. Landscape characterization and zoning based on the results of analysis and synthesis,
7. Categorizing land according to its suitability levels, including classifications such as suitable, unsuitable, precautionary, restricted, and high-risk,
8. Conducting a re-assessment of land cover through overlay analysis based on land use suitability,
9. Identify and draw conclusions,
10. Creating an "Ecological Landscape Master Plan" and making recommendations (Figure 1).

Optimal Suitability Analysis (LANDEP) Method, determination of parameters and criteria:

LANDEP is a comprehensive landscape analysis, synthesis and land-use-optimization system that investigates the most appropriate use of the landscape (Ndubisi, 2002; Tozar, 2006; Tozar et al., 2006; Forman, 2008; Ndubisi, 2014).

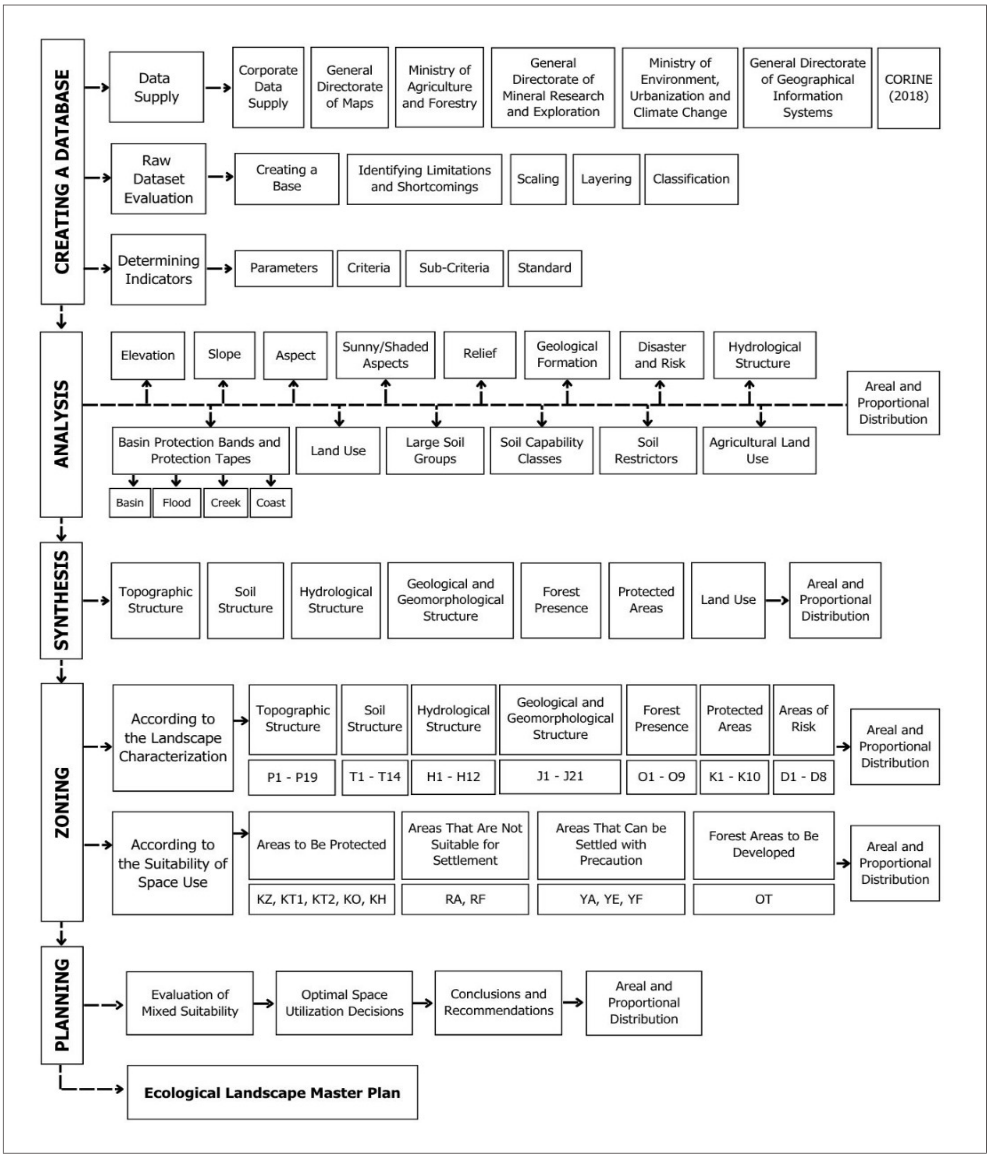

Figure 1. Ecological landscape master plan method scheme.

In ecological planning, it is of great importance to first determine the factors that influence the determination of land uses. Natural components as parameters have been investigated in detail within the scope of approximately 50 studies and 27 literatures according to different specializations.

As common assumptions determined in this context, 8 main parameters, 57 criteria, and other sub-criteria, including topographic, hydrological, soil, geological and geomorphological structure, presence of forest area and forest functions, protected areas, land use were determined and evaluated in the research.

The raw data set was created and homogeneous ecological units were revealed through analysis and synthesis. Similar landscape units were grouped and homogeneous landscape character regions were determined (Table 1).

FINDINGS

Research Area Çınarçık District Location and General Characteristics

The research area covers Çınarcık district of Yalova province, Turkey. It is between 29˚12´40´´ and 29˚18'50´´ east longitude, 40˚37´13´´ and 40˚39´55´´ north latitude and its size is 174 km² (Figure 2), (Yalova Municipality, 2024).

The district covers 4 municipalities, 13 neighborhoods and 4 villages, namely Çalıca, Kocadere, Şenköy, Ortaburun, on the Armutlu Peninsula, an extension of the Northern Anatolian Mountains descending towards the west. It borders the Marmara Sea to the north and is 30 meters above the sea (Yalova Governorship, 2025).

The first traces of settlement in the region belong to 3-4 thousand years BC. Phrygians in 1220 BC, Cimmerians in 700

Table 1. Ecological Landscape Master Plan analysis parameters, criteria and sub-criteria.

Parameter	Criteria	Sub Criteria
Topographic Structure	Slope (%)	0 - 20, 20 - 30, 30 and above
	Orientetion	Sunny (S, SW, SE, E, W) more suitable for settlement, Shady (N, NW, NE) less suitable for settlement
Hydrological Structure	Presence of rivers	Stream Protection Band (150 m) Buffer Zone Settlement Prohibited Area
	Catchment boundary and protection zone	1. Absolute Basin Protection Band (0 -300 m) and 2. Short Distance Catchment Protection Zone (300 - 800 m) area prohibited for settlement
	Flood protection area Flood repetition value (Q)	The area within Q 50, Q 100 and Q 500 values and Flood Protection Zone (250 m) is unfavourable for settlement
	Coastal asset	Coastal Protection Band (100 m) Buffer Zone area forbidden for settlement
	Presence of water surface	Dam, Lake, Pond area forbidden for settlement
	Irrigation area and facilities	Canal and canal settlement prohibited area
Soil Structure	Large land groups	Alluvium and Colluvium Soil 1st degree suitable for agriculture
	Land use capability classes (LUCC) Soil limiting factors	Calcareous Brown Forest Soil-Calcareous Brown Forest Soil not suitable for agriculture
		Class I. ECSC 1st degree suitable for agriculture Absolute Agriculture
		II and III class LUCC, 2nd degree suitable for agriculture
		Class IV LUCC restricted, agriculture can be done with precautions
		Class VI and VII LUCC suitable for settlement
		Class VIII LUCC suitable for forest and meadow-pastur
		Erosion (e) problematic soil
		Wetness (w) problematic soil
		Erosion and Salinity (es) problematic soil
		Soil limited, agriculture can be done with precautions
Geological Structure and Geomorphological Structure	Geological formation Soil liquefaction status	Quaternary sediments, Sarısu Volcanite, Fıstıklı Granite, Arslanbey Formation, Young Alluvial objectionable for settlement
	Fault line presence Fault type	Dead Fault (15 m), Dead Fault Protection Zone (150-500 m) Buffer Zone not suitable for settlement
	Erosion degree Earthquake zone	Grade 3 and 4 high severity erosion not suitable for agriculture
	Earthquake zone	1st degree earthquake zone precautionary habitable area
	Geomorphological unit	Coastal plain, coastal plain, low plateau, high plateau, river valley mountainous area
Forest Asset	Woodland zone boundary and functions	Public health, aesthetics, soil, water and nature conservation, recreation and tourism, forest production, non-forest area, treeless forest area use according to function
Areas to be Protected	Forest presence, stand structure and woody species	Coniferous, broad-leaved and mixed forest Stand type, forest, scrub, heathland
	Floristic structure elements	Endemic plant presence not suitable for settlement
	Agricultural land character, Agricultural pattern	Agricultural areas with wet, dry, irrigated, irrigated, natural vegetation, olive grove, pasture area not suitable for settlement
	Protected area presence, Protection status	National Park, Natural Park, Important Plant Area, Urban, Archaeological and Natural Protected Area prohibited area for settlement
Land Use	Land cover	Settlement, agriculture, forest, meadow and pasture area etc.

S: South; SW: Sout west; SE: South east; E: East; W: West; N: North; NW: North west; NE: North east; LUCC: Land use capability classes; ESCS: European Soil Classification System

BC, Vitrinians in 3 BC, Romans in 74 BC and Turks in 1307 BC. There are many historical monuments such as the Obelisk from the Roman Period, Kocadere Castle and dungeons from the Byzantine Period, churches and monasteries from the Greek Period, Çınarcık Great Mosque from the Ottoman Period, aqueducts and tanks (Yalova Governorship, 2024).

Summers in the region are hot and dry, while winters are mild and rainy. It has a transition feature between the Mediterranean and Black Sea climates. The temperature decreases from the sea coast to the inland and higher elevations, and the annual temperature difference of 14.2 °C increases the diversity of vegetation (Dönmez, 1985).

70% of the area is mountainous and the highest altitude is Dumanlı Hill (987 m) and 11% is the rivers and coastal valleys formed by Deveboynu and Soğuksu, Büyükdere and Taşlimanı streams (Yalova Municipality, 2024).

The Armutlu Peninsula, where the site is located, is dominated by Mediterranean and Euro Siberian flora in terms of floristic structure. In forest areas, broad-leaved woody species such as Hornbeam (*Carpinus betulus*), Chestnut (*Castanea sativa*), Beech (*Fagus orientalis*), White Poplar (*Populus alba*), Ash (*Fraxinus angustifolia*), Linden (*Tilia argentea* Desf ex DC.), Sessile Oak (*Quercus petraea*), Eastern Pine (*Platanus orientalis*) and coniferous woody species such as Larch (*Pinus nigra*), Yellow Pine (*Pinus silvestris*), Pistachio Pine (*Pinus pinea* L.) and Red Pine (*Pinus brutia*) (Bilgin, 1967).

The area, which is 1.5 hours away from Istanbul by private car and 1 hour away from Bursa, is accessible by ferry.

The district's appeal is enhanced by attractions such as the historical Pasha Port, Kocadere, Dikilitaş, Dermaz, Baba, Mersin, Kalem, Çalıvere Cape, Osman Uçuğu, and Engerek Bay; its natural beaches; Erikli, Karlık, and Delmece Plateaus; Sudüşen and Erikli Twin Waterfalls; Hersek Lagoon; Büyük Dipsiz Lake and Küçük Dipsiz Lake; the sacred Ayazma springs; Armutlu Hot Springs; historic forest villages. Yalova's top-priority thermal springs and drinking water sources located just 16 km away.

With its tourism potential due to its accessibility, nature and cultural richness, the winter population is 40632, while the population exceeds 500000 in summer (Yalova Governorship, 2024). Between 1992-2007, the settlement areas on the northern coasts of the Armutlu Peninsula have expanded three times and Çınarcık District is one of them (Özdemir & Bahadır, 2008a). In the 7.4 magnitude 17 August 1999 Izmit Gulf Earthquake, the district was significantly affected due to unplanned construction, building construction conditions according to the soil conditions and non-compliance with the coastal law, etc. (Özdemir & Bahadır, 2008b). The number of deaths in eight provinces including Yalova in the earthquake impact area is 17480 people, 362 people died and 6042 people benefited in Çınarcık District. The total of 628 heavily and 558 moderately damaged buildings in Çınarcık District centre is 4.43% (Özmen, 2000).

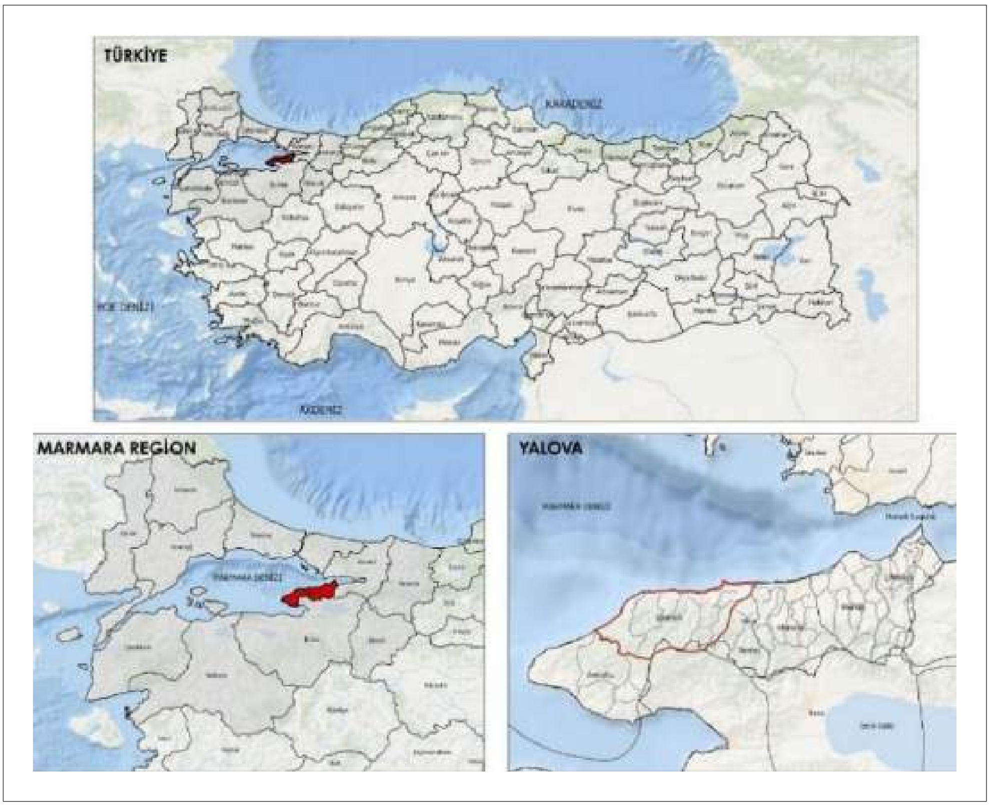

Figure 2. Yalova province and Çınarcık district location.

Landscape Characterization and Zoning

In determining the landscape characterisation of the research area, elevation, slope, aspect, orientation, relief, geological formation, disaster and risk status, hydrology, basin protection area, land use capability, large soil groups, soil limiting factors, current land use cover, agricultural land use and forest presence were analysed (Figure 3).

According to land use, 8% is settlement, 5.7% is marginal agriculture, 4.1% is meadow-pasture, 4% is planted agriculture, 2.1% is absolute agriculture, 1.4% is special crop land, 0.1% is water and 80% is forest area. 70% of the area is mountainous and the highest altitude is Dumanlı Hill (987 m).

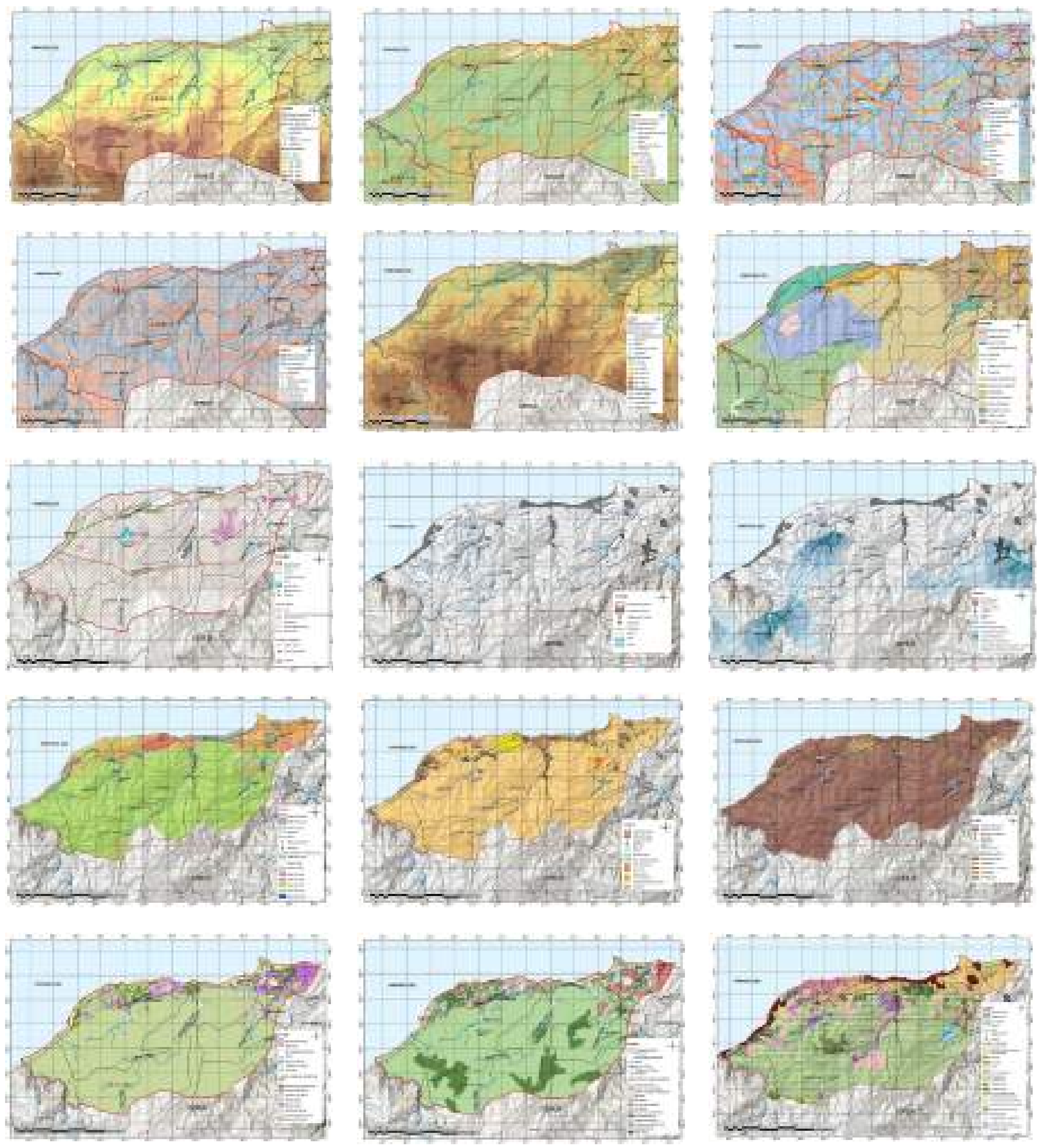

Figure 3. Analysed research area by elevation, slope, aspect, orientation, relief, geological formation, disaster and risk status, hydrology, basin protection area, land use capability, large soil groups, soil limiting factors, current land use cover, agricultural land use and forest presence.*

57% of the area has a slope of over 30%, 11% it is a river and coastal valley formed by Deveboynu and Soğuksu, Büyükdere and Taşlimanı streams. 58% of the settlement area is in coastal plains, plains and valleys at 0-50 m. elevation.

Landscape Characterization and Zoning According to Topographic Structure

Dividing the natural structure into smaller units based on physiographic differences and classifying them in relation to land use, morphology and slope emerge as key parameters. In this context, 19 sub-regions were identified. The P9 region, which comprises 48% of the area, is the largest, characterized by mountainous forest land with slopes over 30%. About 3% of the area corresponds to coastal plain settlements in P1 and P3, 1% to low plateau areas in P14, and 4% to river valley typologies in P3 (Table 2; Figure 4).

Landscape Characterization and Zoning According to Soil Structure

Soil structure is a key parameter in determining the suitability of areas for settlement, absolute agricultural use, and forestry, as well as in identifying appropriate growing environments (T.C. Resmi Gazete, 2005; T.C. Resmi Gazete, 2017).

According to the Handbook on Integration of Geoscientific Data into Planning and Provincial Disaster Risk Reduction Plan Preparation Guide Module 1, soils in Class I, II and III land capability are areas unsuitable for settlement (UOA) (Afet İşleri Genel Müdürlüğü, 2006; İl Planlama ve Risk Azaltma Daire Başkanlığı, 2020).

These areas are "Absolute Agricultural" areas that should definitely be used for agricultural activities. Accordingly, sub-regions were determined by taking large soil groups, land use capability classes and soil limiting factors as criteria in zoning.

Landscape Characterization and Zoning According to Major Soil Groups

In terms of major soil groups, there are 5 different soil types in the area: Alluvial, colluvial, brown forest soils, brown soils without lime and rendzinas.

Brown forest soils develop on calcareous bedrock and are generally found on very steep, rugged slopes. Due to their shallow to very shallow depth, they are prone to severe erosion and stoniness problems (T.C. Resmi Gazete, 2005). They make up 3% of the area and are used as forest, shrubland, and pasture. On suitable slopes, they can also

Table 2. Zoning according to topographic structure, areal and proportional distribution.

Subregion	Criteria and Sub Criteria			Area (ha)	Ratio (%)
	Land Use	Morphological Structure	Slope Groups (%)		
P1	Settlement	Coastal plain	0-30	272	2
P2	Settlement	Stream valley	0-30	29	0.2
P3	Settlement	Coastal plain	30 and above	242	1
P4	Agriculture	Coastal plain	0-30	615	4
P5	Agriculture	Stream valley	0-30	825	5
P6	Agriculture	Mountainous area	0-30	414	2
P7	Agriculture	Mountainous area	30 and above	563	3
P8	Forest	Mountainous area	0-30	2523	15
P9	Forest	Mountainous area	30 and above	8002	48
P10	Forest	Stream valley	0-30	322	2
P11	Forest	Stream valley	30 and above	863	5
P12	Forest	High plateau	30 and above	423	3
P13	Forest	High plateau	0-30	242	1
P14	Settlement	Low plateau	0-30	95	1
P15	Agriculture	Low plateau	0-30	642	4
P16	Forest	Low plateau	0-30	308	2
P17	Forest	Coastal plain	0-30	98	1
P18	Forest	Coastal plain	30 and above	113	1
P19	Agriculture	Coastal plain	30 and above	201	1
Total				1679	

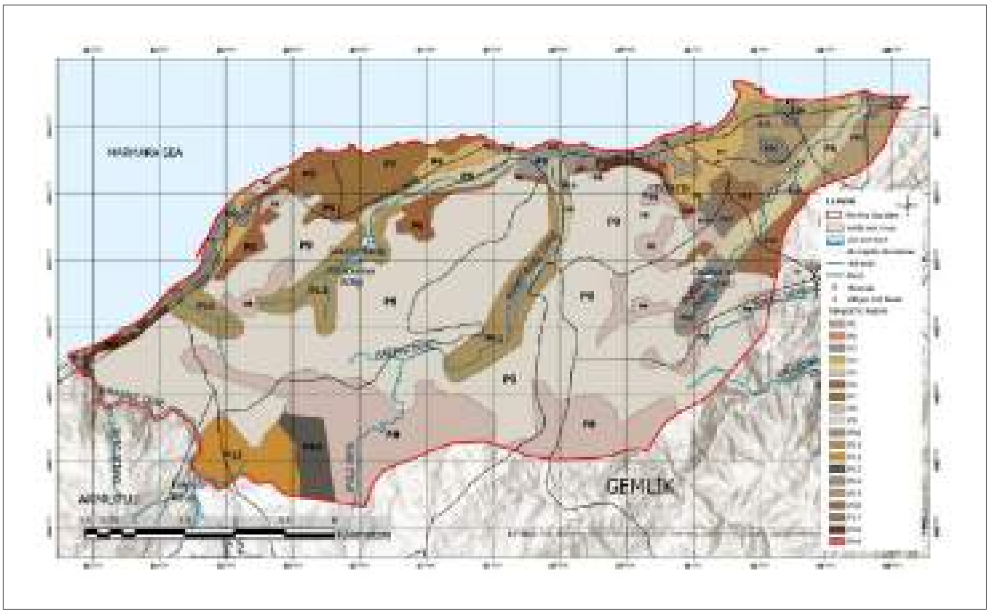

Figure 4. Agricultural land use analysis.

be used for dry farming and fruit cultivation. Brown forest soils without lime, meadow forest lands are transitional soils and generally shallow and shallow soils. The natural vegetation is dominated by forest cover and meadow plants, coniferous forests and meadow formation maquis.

Alluvial soils are deep, flat and nearly flat sloping with little or no erosion hazard. They have good water permeability, rich in mineral and organic matter and fertile. Since they are suitable for growing all kinds of cultivated plants, they have a very high agricultural value It is 19% in the area and is observed in the coastal areas of Çınarcık center settlement, Ortaburun and Esenköy.

Colluvial soils are formed by the accumulation of eroded materials from slopes at the foothills where the gradient decreases. They contain fine materials such as sand, clay and shale in different sizes and have good drainage as they are located in sloping areas. They have agricultural value and can generally be used as dry agricultural land (T.C. Resmi Gazete, 2005). They make up 5% of the area, and the colluvial soils with Class I land capability are considered fertile for agricultural production due to their high mineral content and strong water retention capacity.

Rendzinas are located on medium to high slopes and have low water retention capacity due to the compact nature of the bedrock. Plants can often be damaged by drought, they rapidly lose their organic matter when cultivated and may be subject to severe erosion (T.C. Resmi Gazete, 2005). In the area, these soils are 3 ha and 1% is in Teşvikiye town. In 68% of the area, the land is used as forest and pasture, and agriculture can be practiced on slopes with suitable gradients.

Landscape Characterization and Zoning According to Land Use Capability

In order to ensure the proper use of agricultural lands, soils are classified according to their importance for agricultural use. Land use capability is an important parameter that determines the necessary protection measures and the limits of suitability according to soil cultivation and use patterns. The first four classes of lands have a good soil structure, cultivated plants adapted to the region and forest and meadow plants can be grown well. Class III and IV lands are the last limit of irrigable agricultural lands. They have problems such as erosion and slope, and are less suitable for agriculture compared to Class I and II lands. Especially in sloping areas, problems such as shallowness, stoniness and flooding are noticeable. Class V, VI and VII lands are suitable for the growth of natural vegetation adapted to the region. Some special cultivated plants can also be grown in Class V and VI lands by taking necessary water and protection measures. Class VIII lands are generally lands where there is no or very little soil cover and agriculture is very difficult and uneconomical (T.C. Resmi Gazete, 2005).

The total of the first three classes of land with high productivity in terms of soil capability in the area is 15%. Class I is very limited with 3%, Class II with 1% and Class III with 11%. Soils where crops such as shrubs and trees are grown are class IV land with a rate of 13%. 33% of class VI and 43% of class VII soils are not suitable for agricultural production and are used as forest land

Landscape Characterization and Zoning According to Soil Limiting Factors

In terms of agricultural performance, soil limiting factors erosion, wetness, stoniness, salinity are important parameters. They are the factors that determine the agricultural pattern and agricultural feasibility according to their single and/or coexistence in the soil structure. The soil limiting factor that restricts agricultural activities and is dominant in 87% of the area is erosion-salinity. Erosion factor is effective in Kocadere and Çalıca locations in 4 ha area with a rate of 10%. Wetness factor is in the coastal areas of Şenköy, Çalıca, Koru, Teşvikiye towns and Çınarcık center settlement in 1 ha area. Land use, large soil groups, land use capability classes (LUUC), soil limiting factors were taken as criteria in zoning and 14 sub-regions were determined. T14 region is forest area, non-calcareous forest soil and class VII land and is the largest sub-region with 71%. T13 is the second largest sub-region with 15% of agricultural area, non-calcareous brown forest soil and class VI land. In both regions, erosion and salinity are the major limiting factors (Table 3; Figure 5).

Landscape Characterization and Zoning According to Hydrological Structure

An important parameter related to hydrological structure in the process of making land use decisions is the presence of a watershed. According to the EU Water Directive, the Flood Regulation and the Flood Protection Law, flood risk potential should be determined in river basins and areas exposed to flooding (Water Directive, 2007; T.C. Resmi Gazete, 2021; T.C. Resmi Gazete, 2016). According to the Regulation on Preparation, Implementation and Monitoring of Basin Management Plans, basin areas are water catchment areas. They have the functions of controlling erosion and flooding in the rainfall basin and producing water of good quality and quantity (T.C. Resmî Gazete, 2012). Appropriate land use types and conditions have been determined according to 4 protection distances in the basins. According to İRAP Module 1, water catchment basins and 1st and 2nd degree basin protection bands should be determined in terms of settleability (İl Planlama ve Risk Azaltma Daire Başkanlığı, 2020). 1st Degree Basin Protection Zone: The 'Absolute Protection Area' consists of natural and artificial water bodies used for drinking and utility water supply, and includes a land strip 300 meters wide measured horizontally from the line where land meets water. 2nd Degree Basin Protection Zone: "Short Distance Protection Area" is the land area 700 m wide horizontally from the upper limit of the absolute protection area.

In both protection bands, settlement, agriculture, tourism and mining cannot be carried out in any way except for treatment facilities, and cemeteries cannot be established. Organic agriculture may be allowed in the short-distance protection area under the supervision of the relevant insti-

Table 3. Areal and proportional distribution of zoning according to soil structure.

Subregion	Criteria and Sub Criteria				Area (ha)	Ratio (%)
	Land Use	Large Soil Groups	Capability Class	Limiting Factors		
T1	Settlement	-	-	-	569	3.24
T2	Agriculture	Alluvial	III	Wetness (w)	59	0.34
T3	Forest	Brown Forest Soil	III	Erosion and Salinity (es)	65	0.37
T4	Agriculture	Brown Forest Soil	III	Erosion and Salinity (es))	85	0.48
T5	Agriculture	Colluvial	I	-	16	0.09
T6	Olive grove	Brown Forest Soil	VII	Erosion and Salinity (es)	198	1.13
T7	Forest	Brown Forest Soil	II	Erosion (e)	23	0.13
T8	Forest	Alluvial	II	Wetness (w)	54	0.31
T9	Agriculture	Calcareous Brown Forest Soil	IV	Erosion and Salinity (es)	94	0.53
T10	Agriculture	Colluvial	III	Erosion (e)	247	1.41
T11	Agriculture	Calcareous Brown Forest Soil	III	Erosion (e)	137	0.78
T12	Forest	Calcareous Brown Forest Soil	VII	-	855	4.86
T13	Agriculture	Calcareous Brown Forest Soil	VI	Erosion and Salinity (es)	2.646	15.05
T14	Forest	Calcareous Brown Forest Soil	VII	Erosion and Salinity (es)	12.530	71.28
				Total	17,578	

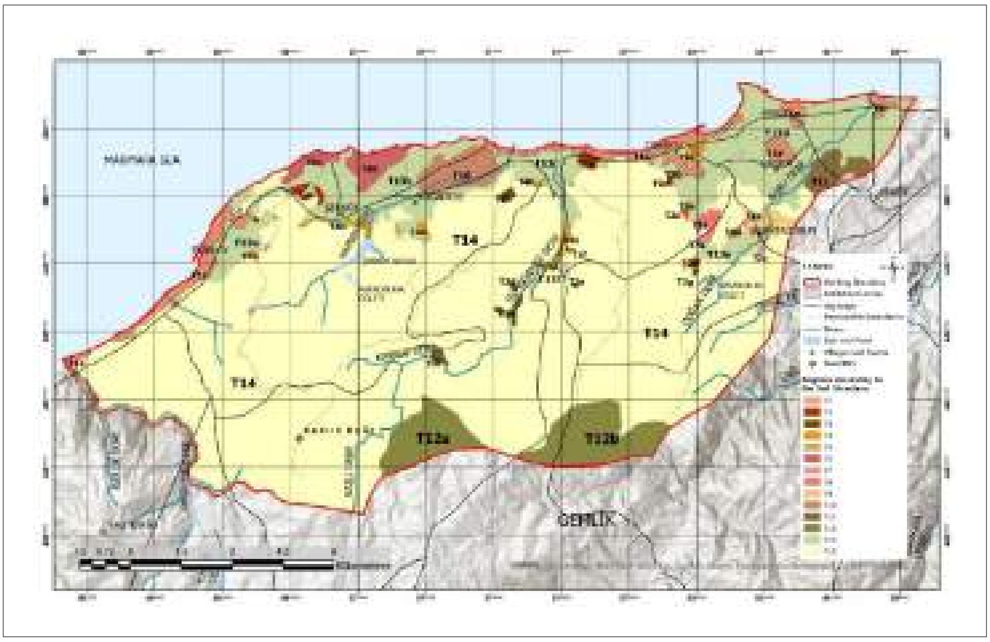

Figure 5. Landscape characterization and zoning according to soil structure.

tution (T.C. Resmî Gazete, 2012). Peak flow and flood recurrence intervals (Q value) are important parameters in determining flood risk areas according to water surface elevations in spatial plans at all levels (Water Directive, 2007; T.C. Resmî Gazete, 2014; T.C. Resmi Gazete, 2021).

Q max. project flow is 10 and headroom is 50 in the fields, 100 and headroom is 500 in villages, 500 and headroom is 1000 in big cities. Once in 100 years, areas subject to very rare and very high probability flooding should be identified (T.C. Resmi Gazete, 2016). River and coastal protection zone (250 m) is another important criterion (İl Planlama ve Risk Azaltma Daire Başkanlığı, 2020).

The coastal protection zone in the area is 32 km, 18 km of which is settlement area. Şenköy Dam (30 ha) is the most important water surface in the area. Basin protection bands cover an area of 16 ha and 10% is absolute protection, 19% is short, 25% is medium and 46% is long distance protection area.

In zoning, 12 sub-regions were determined by taking land use, watershed boundary, watershed, river and coastal protection bands, and irrigation areas as criteria. H10 zone is in forest use and occupies the largest area with 31.4%. H5 and H6 zones with 18% are in watershed protection band and forest area. H1, H4 and H11 zones with 4% are in river and coastal protection band and settlement area (Table 4; Figure 6).

Landscape Characterization and Zoning According to Geological and Geomorphological Structure

In terms of disaster history, 42 earthquakes of magnitude 6.8 and above and 24 tsunamis have occurred in the region since 400 AD (Sancaklı, 2004).

The Çınarcık Trench in the Sea of Marmara and the presence of the North Anatolian Fault Line (NAF), one of the most seismically resilient faults in the world, carry the risk of severe earthquakes and tsunamis (Gazioğlu et al., 2005).

The active fault is the most significant structural feature of the neotectonic formations surrounding the Armutlu Peninsula. It is divided into two branches, north and south, in the Armutlu Peninsula. One branch is located in Yalova region and continues in the Marmara Sea depressions in the east-west direction (Figure 7), (Emre, 1999).

In the area, the upper system of the geological structure belongs to the Cenozoic era, with the system classified as Quaternary, the series as Holocene, and four formations identified: Sarısu Volcanics (Ts), Fıstıklı Granite, Arslanbey Formation (Ta), and Alluvium (Qal). According to the proportional size of the geological formations, Sarısu Volcanites dominate with 44% and Fıstıklı Granite with 25%. The Arslanbey and Alluvium formations, which cover 13% of the area, are prone to liquefaction and are considered unsuitable for settlement. Alluvial soils contain clay, silt and sandstone, the most liquefaction prone soils are fine sands and silty sands. In general, clay soils are not susceptible to liquefaction, but they lose their strength during earthquake shaking and move to the surface with liquefying sands (Koç, 2007). Areas with liquefaction potential are defined as areas that are not suitable for settlement due to disaster hazards (UOA) and require detailed geological-geotechnical survey (DGI) and microzonation (İl Planlama ve Risk Azaltma Daire Başkanlığı, 2020). Approximately all of the built-up area in the area is on young alluvial soils and are areas with precautionary conditions and problematic areas such as swelling, settlement, liquefaction etc. where precautions can be taken.

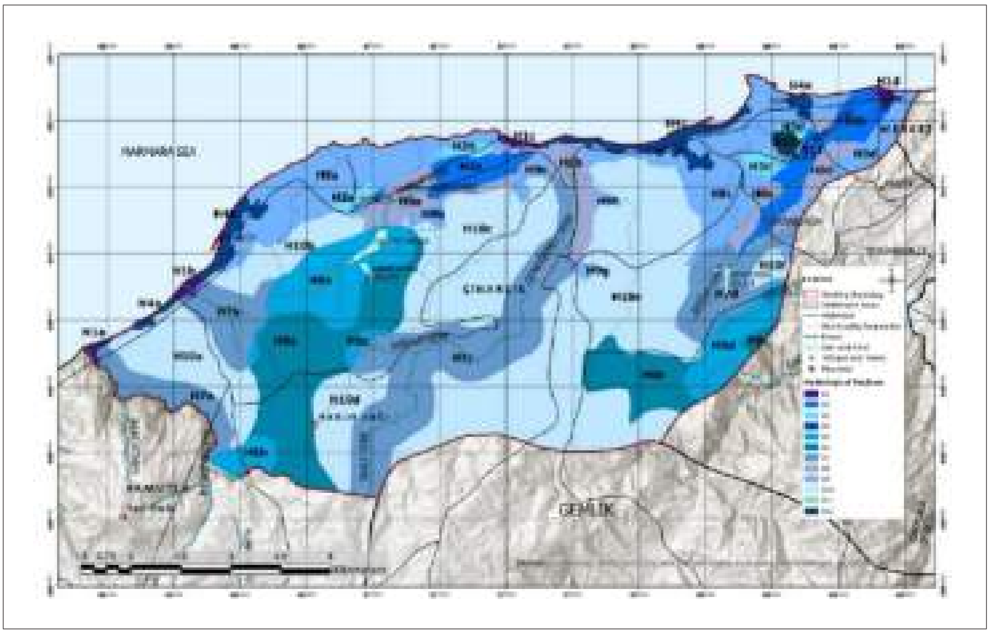

Figure 6. Landscape characterization and zoning according to soil structure.

Sarısu volcanics are widespread in the central part of the Armutlu Peninsula and are volcanic stacks consisting of andesitic lavas and agglomerates. This formation starts with a sedimentary level usually 5-10 m thick on metamorphic rocks. It consists of lithologies such as conglomerate, mudstone, sandstone and limestone and is problematic in terms of settleability (Yılmaz et al., 2010). Fıstıklı granite contains granitic rocks with different mineralogical compositions and is therefore suitable for settleability (Dereköy, 2006). Merkez Neighbourhood and Koru town are located on young alluvial soil and coastline with liquefaction potential. With over 4 storeys high-rise building stock and high ground magnification values, these are the neighborhoods that will be most affected by a possible major earthquake.

In the zoning process, 21 sub-regions were identified based on criteria including land use types such as settlement areas, forests, and agricultural lands; landslide risk zones; geological formations such as Quaternary deposits; erosion risk areas and their severity; and the presence of fault protection

Table 4. Zoning according to hydrological structure, areal and proportional distribution.

Subregion	Criteria and Sub Criteria					Area (ha)	Ratio (%)
	Land Use	Basin Protection Band	Stream Protection Band	Coastal Protection Band	Irrigation Area		
H1	Settlement		+	+		100	0.57
H2	Settlement		+		+	815	4.63
H3	Agriculture				+	199	1.13
H4	Settlement			+		469	2.67
H5	Forest	+	+			1353	7.70
H6	Forest	+				1834	10.43
H7	Forest		+			2933	16.69
H8	Agriculture		+			996	5.67
H9	Agriculture					3300	18.77
H10	Forest					5520	31.40
H11	Settlement		+			5	0.03
H12	Settlement					54	0.31
Total						17578	

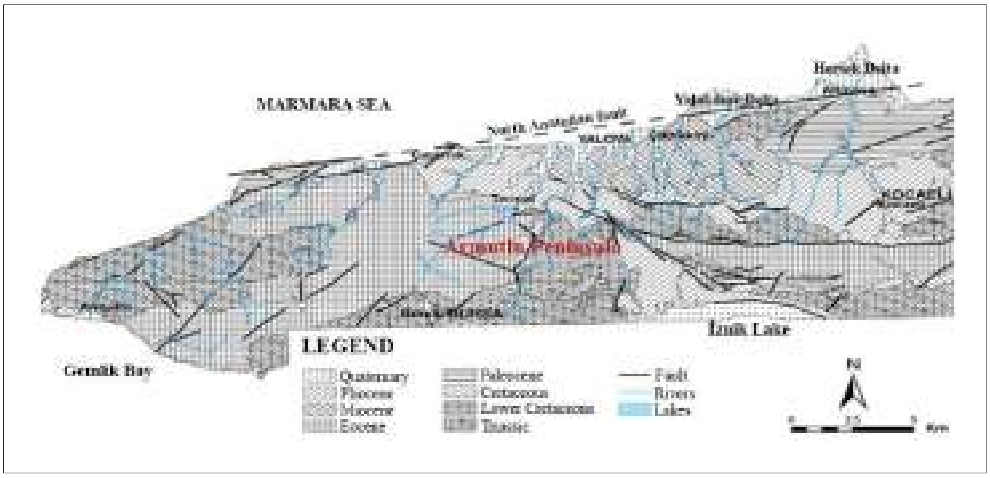

Figure 7. Geological map of Armutlu Peninsula (Özdemir & Bahadır, 2008a).

zones. J5 region covers 69.6% of the area and is the largest region with forest area and 3rd degree erosion risk. J1, J2, J4, J14, J16 and J19, which cover 5% of the area, are built-up areas, quaternary sediments, 3rd degree erosion or fault protection zone and earthquake risk areas. J20 zone is 1.2% of the area and is a landslide risk area. Ortaca Village settlement area is in this landslide risk zone (Table 5; Figure 8).

Landscape Characterisation According to Forest Areas and

Table 5. Zoning according to geological and geomorphological structure, areal and proportional distribution.

Subregion	Criteria and Sub Criteria					Area (ha)	Ratio (%)
	Land Use	Landslide Risk Area	Geological Formation	Erosion Degree	Protection Band		
J1	Settlement		Quaternary	3		35	0.2
J2	Settlement				+	24	0.1
J3	Forest			4		74	0.4
J4	Settlement		Quaternary		+	390	2.2
J5	Forest			3		12460	69.6
J6	Forest			3	+	187	1.0
J7	Forest	+		3		374	2.1
J8	Forest		Quaternary	3		368	2.1
J9	Agriculture		Quaternary			277	1.5
J10	Agriculture		Quaternary	3	+	33	0.2
J11	Agriculture			3		149	0.8
J12	Agriculture		Quaternary	3		821	4.6
J13	Agriculture	+		3		1735	9.7
J14	Settlement		Quaternary			209	1.2
J15	Agriculture			3	+	264	1.5
J16	Settlement			3	+	190	1.1
J17	Settlement					181	1.0
J18	Agriculture					86	0.5
J19	Settlement			3		32	0.2
J20	Settlement	+				15	0.1
J21	Agriculture	+				4	0.02
						Total 17907.30	

Figure 8. Landscape characterisation and zoning according to geology and geomorphological structure.

Functions 15% of the forest areas are in agriculture and olive grove production function and 3% of them have 16 endemic plant species.

The treeless forest area is located in Esenköy; the water protection zone surrounds the Ortaburun Pond; forests with agricultural-aesthetic functions are found around the central settlement; and the ecotourism area lies within the Armutlu district boundary.

In zoning, 9 sub-regions were determined according to land use and endemic plant species. The O3 region, which covers 58% of the area, is the largest area harbouring endemic species. O4 and O9 are agricultural areas covering 3% of the area and harbouring endemic species (Table 6; Figure 9).

Landscape Characterisation and Zoning According to Protected Areas

In the zoning, 10 regions and 26 sub-regions were determined according to land use, hydrology, protection bands and area criteria.

In the protected areas, 38% of the K4 region is under forest land use and covers the largest area.

Sub-region K1a is the only protected area with Şenköy Grade II Archaeological Site (Table 7; Figure 10).

Landscape Characterisation and Zoning According to Risk Factors

According to the disaster regulations and guidelines with

Table 6. Areal and proportional distribution of forest areas according to their functions**.**

Subregion	Criteria and Sub Criteria		Area (ha)	Ratio (%)
	Land Use	Endemic Species Presence		
O1	Forest	-	841	5
O2	Agriculture	-	2080	12
O3	Forest	+	9862	58
O4	Agriculture	+	90	1
O5	Forest	-	1455	9
O6	Agriculture	-	418	2
O7	Olive grove	-	196	1
O8	Forest	-	1737	10
O9	Agriculture	+	261	2
Total			1690	

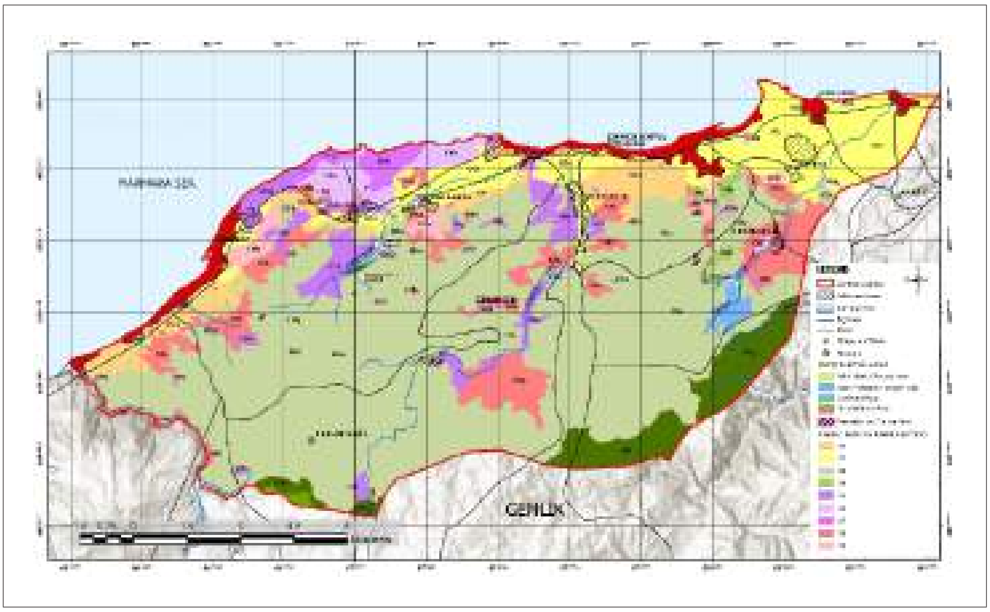

Figure 9. Landscape characterization and zoning of forest areas according to their functions.

the definition of 'Critical Area', lands within 15 m distance to fault lines, having geological structure that will increase earthquake intensity or having liquefaction potential cannot be subject to priority or intensive development (İstanbul Büyükşehir Belediyesi, 2002; Japon Uluslararası İşbirliği Ajansı, 2004; T.C. Resmî Gazete, 2007; İstanbul Valiliği, 2014; Afet ve Acil Durum Yönetimi Başkanlığı, 2023).

According to the maps of live fault lines, the areas within 15 m from the fault lines are determined as fault protection bands and are considered as areas unsuitable for settlement (Maden Tetkik Araştırma Müdürlüğü, 2019).

In terms of settleability, areas with slopes above 18-20% are problematic and precautionary areas. In terms of another type of disaster, there is a regional landslide risk in the zones dominated by geological formations with high slopes and suitable for weathering, low slopes and rich in alluvial sediments (İl Planlama ve Risk Azaltma Daire Başkanlığı, 2020).

Areas at risk of disaster are areas that are not suitable for settlement (UOA) and require detailed geological-geotechnical survey (DGI) and microzoning (MBA) (T.C. Resmî Gazete, 2014).

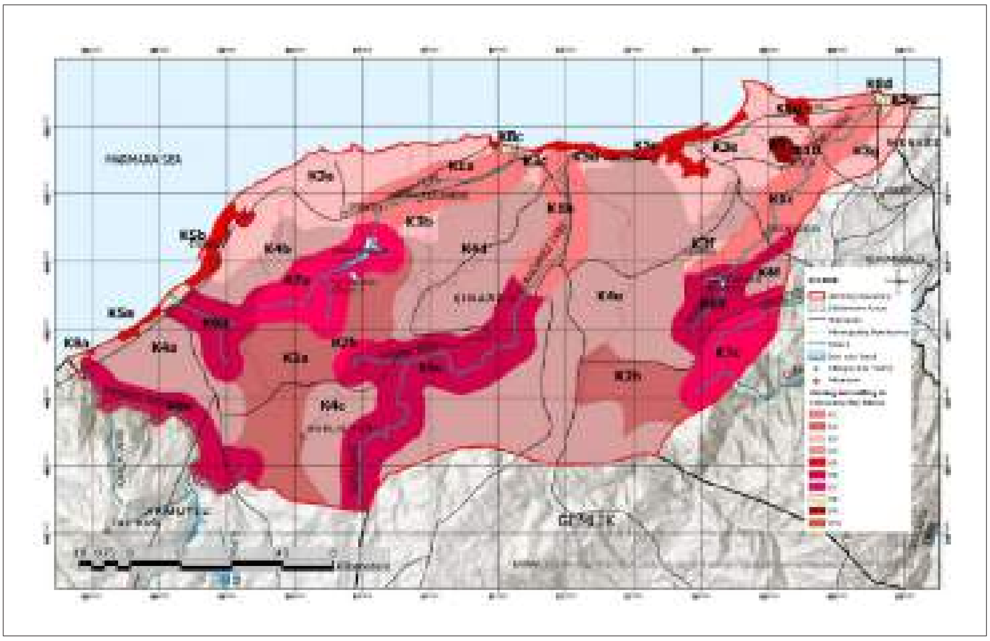

Figure 10. Landscape characterisation and zoning according to protected areas.

Table 7. Zoning, area and proportional distribution by protected areas.

Region	Subregion	Land Use	Areas to be Protected				Area (ha)	Ratio (%)	Ratio (%)
			Hydrological Protection Bands	Forest Area	Agriculture Area	Protection Site			
K1	K1a	Agriculture	Stream	-	+	+	310	1.76	5.67
	K1b	Agriculture	Stream	-	+	-	261	1.48	
	K1c	Agriculture	Stream	-	+	-	425	2.42	
K2	K2a	Forest	Basin	+	-	-	1158	6.59	10.43
	K2b	Forest	Basin	+	-	-	676	3.85	
K3	K3a	Agriculture	-	-	+	-	1573	8.95	18.26
	K3b	Agriculture	-	-	+	-	62	0.35	
	K3c	Agriculture	-	-	+	-	37	0.21	
	K3d	Agriculture	-	-	+	-	43	0.24	
	K3e	Agriculture	-	-	+	-	1240	7.05	
	K3f	Agriculture	-	-	+	-	31	0.18	
	K3g	Agriculture	-	-	+	-	224	1.27	
K4	K4a	Forest	-	+	-	-	552	3.14	38.50
	K4b	Forest	-	+	-	-	426	2.42	
	K4c	Forest	-	+	-	-	412	2.34	
	K4d	Forest	-	+	-	-	1350	7.68	
	K4e	Forest	-	+	-	-	3908	22.23	
	K4f	Forest	-	+	-	-	120	0.68	
K5	K5a	Settlement	Coastal	-	-	-	40	0.23	2.47
	K5b	Settlement	Coastal	-	-	-	112	0.64	
	K5c	Settlement	Coastal	-	-	-	236	1.35	
	K5d	Settlement	Coastal	-	-	-	40	0.23	
	K5e	Settlement	Coastal	-	-	-	5	0.03	
K6	K6a	Forest	Stream	+	-	-	561	3.19	16.51
	K6b	Forest	Stream	+	-	-	430	2.45	
	K6c	Forest	Stream	+	-	-	1463	8.32	
	K6d	Forest	Stream	+	-	-	448	2.55	
K7	K7a	Forest	Basin, Stream	+	-	-	741	4.22	7.31
	K7b	Forest	Basin, Stream	+	-	-	50	0.28	
	K7c	Forest	Basin, Stream	+	-	-	494	2.81	
K8	K8a	Settlement	Coastal, Stream	-	-	-	21	0.12	0.54
	K8b	Forest	Coastal, Stream	-	-	-	32	0.18	
	K8c	Settlement	Coastal, Stream	-	-	-	18	0.10	
K9	K9	Forest	-	-	-	-	49	0.28	0.28
K10	K10	Settlement	Stream	-	-	-	6	0.03	0.03
Total 1758									

In the zoning, 8 sub-regions were determined according to land use and disaster risk factors. In terms of risky areas, D3 sub-region in the river and basin protection band is the largest area with 40% and D5 sub-region with 3rd degree erosion risk is the largest area with 10% in terms of settlement, forest and agricultural areas.

Sub-region D7 is the second largest area with 38% of forest area and 3rd degree erosion risk. D1 sub-region is in the built-up area and this area, which is in the quaternary sediment and fault line protection band, is objectionable in terms of geological formation, has a rate of 1% (Table 8; Figure 11).

ÇINARCIK DISTINCT ECOLOGICAL LANDSCAPE MASTER PLAN

In terms of landscape characterisation, there are 7 regions and a total of 93 sub-regions determined according to topographic structure (19), soil structure (14), geology and geomorphological structure (21), hydrological structure (12), forest presence (9), protection area (10) and risky areas (8). Within the scope of the Ecological Master Plan, these areas are evaluated under 4 sub-headings as areas to be protected, unsuitable for settlement, areas that can be settled with limited-precaution and areas where forest presence will be developed, and land use decisions and recommendations are made according to their ecological suitability.

Areas to be Protected in Çınarcık District (K)

Five sub-regions were determined according to land use, soil structure and basin protection band criteria and it is the largest region of the area with 60.8%.

KZ Zone: It consists of T6 and O7 sub-regions and covers 1.1% of the area. T6 region has the characteristics of brown forest soil, class VII soil, erosion and salinity factor. Existing agricultural land use will continue, but soil limiting problems need to be improved. O7 is an olive grove area, and its agriculture and nature conservation function should be maintained.

KT1 Region: It consists of T5, T9 and T10 sub-regions covering 2.03% of the area under agricultural land use. T5 region is colluvial soil and class I soil. T9 region is non-calcareous brown forest soil, class II soil, erosion and salinity problematic. T10 region is colluvial soil, class III soil, erosion problematic. Agricultural activities should be continued in the region by eliminating soil problems, non-agricultural activities should not be allowed and it should be protected as an absolute agricultural area.

KT2 Region: It consists of T2, T4, T11 and T13 sub-regions covering 16.6% of the area under agricultural land use. T2 region agricultural area is alluvial soil, class III soil and the limiting factor is wetness. T4 region is agricultural area, brown forest soil, class III soil and limiting factors are erosion and salinity. T11 zone, agricultural area, brown forest soil without lime, class III soil and erosion is problematic. T13 zone, agricultural area, non-calcareous brown forest soil, class VI soil and erosion and salinity are problematic. The region is suitable for agricultural activities by eliminating soil limiting problems in terms of agricultural performance.

KO Region: It covers O1, O3, O5 and O8 sub-regions in forest land use. It is the largest area with 23% and forest protection status will continue.

KH Region: It is in forest land use and in the catchment protection band and covers H5 and H6 zones and 18.1% of the area. Protection status in terms of soil and water functions and ecosystem services (Table 9; Figure 12).

Unsuitable Areas for Settlement

The Unsuitable Areas for Settlement (UOA) Region consists of two sub-regions covering 37.1% of the area. It carries hazards such as earthquake, landslide, flood and tsunami due to geology, geomorphology and hydrological structure. The region is an area of exposure in terms of disaster risks and is not suitable for settlement (Table 9; Figure 12).

Table 8. Zoning according to risk factors, areal and proportional distribution.

Landscape Character Zones	Criteria and Sub Criteria		Area (ha)	Ratio (%)
	Land Use	Risk Factor		
D1	Settlement	Geological formation quaternary sediment Fault line protection zone	197	1
D2	Forest	Landslide risk area	350	2
D3	Settlement, Forest, Agriculture	Stream protection zone Basin protection zone	7016	40
D4	Agriculture	Fault line protection zone	589	3
D5	Forest, Settlement, Agriculture	3rd degree erosion risk area	1759	10
D6	Olive grove	Absolute protection required area	188	1
D7	Forest	3rd degree erosion risk area	6674	38
D8	Forest	-	782	4
Total 17555				

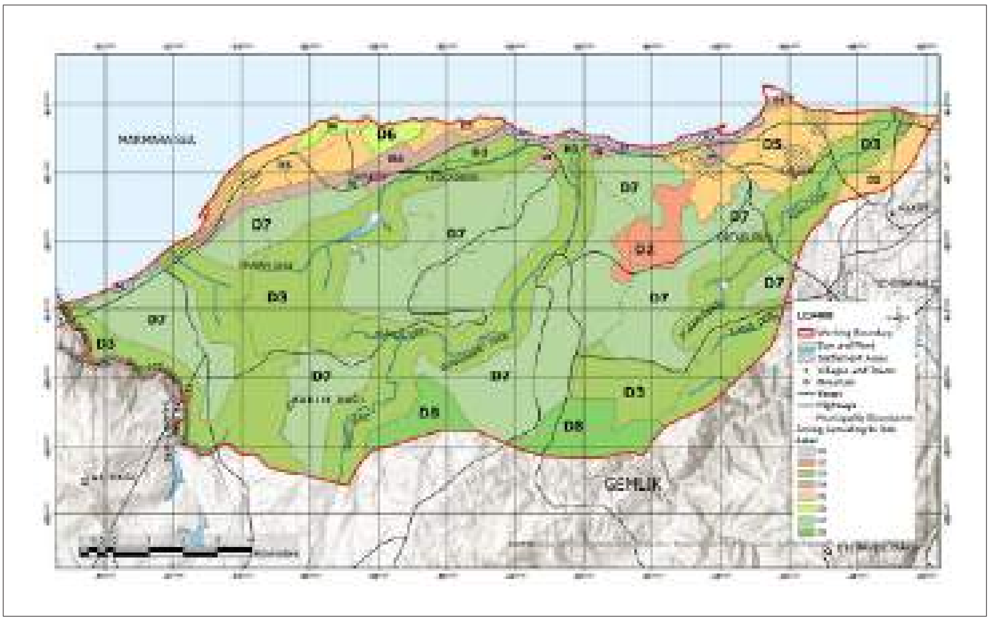

Figure 11. Landscape characterisation and zoning according to risk factors.

RA Zone: It covers sub-regions H2, H5, H7 and H8 in the river protection band and 34.7% of the area. H2 zone is agriculture and irrigation area, H5 zone is forest area, basin and river protection band, H7 zone is forest area and river protection band, H8 zone is agriculture area and river and coastal protection band.

RF Zone: J2 and J4 sub-regions on the live fault line and in the fault line protection band and covers 2.4% of the area. J2 zone is in built-up area and fault line protection band. J4 zone is built-up area, geological formation is quaternary sediment and fault line is in the protection band.

Areas Suitable for Settlement in Limited Conditions with Precautions (PSA)

According to the risk factors, the precautionary settlements areas (PSA) zone consists of four sub-zones covering 1.8% of the area. In these areas, microzonation and drilling data, soil structure and liquefaction analyses, etc. should be carried out to determine new construction conditions. The region covers areas that are limitedly inhabitable and require Detailed Geological Investigation (DGI) (Table 9; Figure 12).

YA Region: It is built-up areas and is in the river and coastal protection band. It covers H1 sub-region and 0.5% of the area.

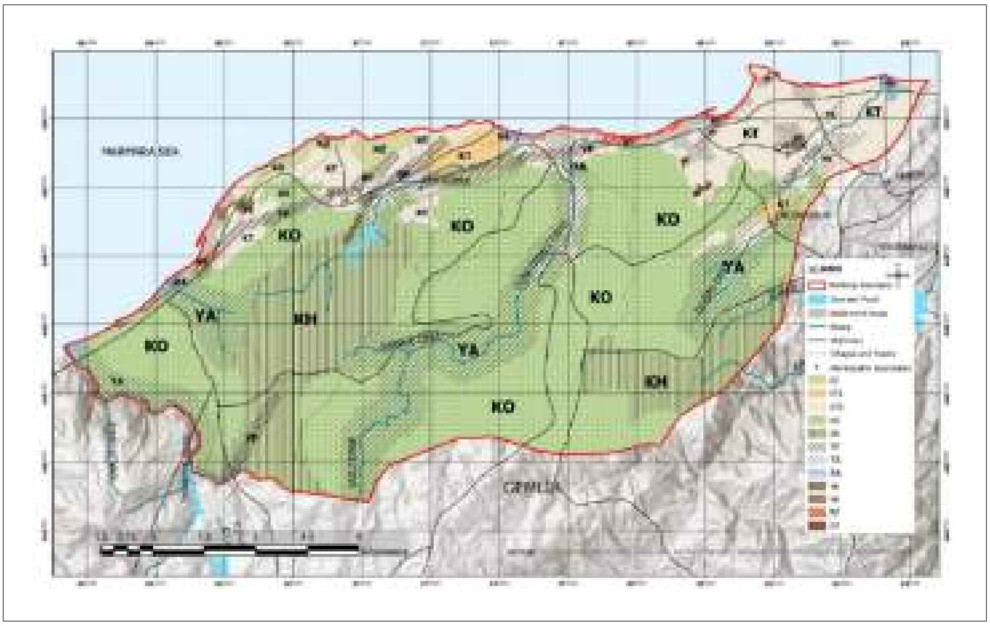

Figure 12. Ecological Landscape Master Plan according to land use suitability zoning.

Table 9. Land use suitability zoning and distribution of parameters.

Zones	Subregion	Criteria	Subregions	Area (ha)	Ratio (%)
Area to be protected (K)	KZ	Agricultural area	T6	198	1.1
		Forest area Olive grove use	O7		
	KT1	Agricultural area	T5, T9, T10	357	2.03
	KT2	Agricultural area	T2, T4, T11, T1	2927	16.6
	KO	Forest area	O1, O3, O5, O8	4037	23
	KH	Settlement area Basin protection band	H5	3187	18.1
		Forest area Basin protection band	H6		
Total				10706	60.8
Unsuitable areas for settlement (UOA)	RA	Agricultural area Stream protection band	H2, H8	6098	34.7
		Forest area Stream protection band	H5, H7		
	RF	Settlement area Fault protection band	J2, J4	414	2.4
Total				6512	37.1
Residential area with precaution (PSA)	YA	Settlement area Stream protection band	H1	100	0.5
	YE	Settlement area Erosion risk area	J1, J20	50	0.3
	YH	Agricultural area Landslide risk area	J21	4	0.02
	YF	Settlement area Fault protection band	J16	190	1
Total				344	1.8
Forest area to be developed (OT)	OT	Forest area status Treeless forest soil	T5	16	0.09
Total				16	0.09

YE Zone: Built-up areas with erosion risk, covering J1, J20 sub-regions and 0.3% of the area. J1 region is quaternary sedimentary and has earthquake risk and 3rd degree erosion problem. J20 zone is at risk of landslide.

YH Zone: It has landslide risk and is in agricultural use. J21 zone covers 0.02% of the area.

YF Zone: 3rd degree erosion risk, in fault line protection band and in settlement use. J16 landscape character sub-region covers 1% of the area.

Treeless Forest Land to be Developed

It is treeless forest land (OT) and there is no vegetation cover on it, but it is a forest area and has a protection status. OT Zone: The lands in this region are colluvial soil and class I land use capability. It covers the T5 landscape character sub-region and 0.09% of the area. In terms of land use, this area is 16 ha and it is an area to be developed by afforestation (Table 9; Figure 12).

CONCLUSION AND RECOMMENDATIONS

Çınarcık District has disaster potentials in terms of risk factors such as earthquake, flood, landslide, tsunami and erosion in 83% of the survey area: Almost all of the inhabited area of the district center is on young alluvial soils. Construction conditions are limited, controlled and problematic areas with swelling, settlement, filling, etc. that require precautions. Areas with liquefaction potential are unsuitable for settlement (UOA) due to disaster hazards, and detailed geological-geotechnical survey (DGI) and microzonation are required in terms of seismicity.

58% of the settlement is in coastal plains, coastal plain and river valleys at 0-50 m elevation. Unsuitable for settlement area (UOA) accounts for 37.1% of the area. For effective management of tsunami, flood and flood risk in these areas, hazardous areas should be analyzed in detail according to topographical, hydrological, climatic and other relevant factors. Flood susceptibility maps should be created with accurate geographical information and indicators and necessary measures should be taken in flood vulnerability areas. It is necessary to declare the risky areas determined according to the disaster situation as "Disaster Vulnerability Areas" and urgently evacuate the risky buildings according to the building stock. It is of great importance to determine the reconstruction conditions of the buildings that have expired through microzonation and detailed geological surveys.

Decentralization to suitable areas in terms of settleability is necessary according to the size of the population that may be affected in areas exposed to risks. However, the most important problem in the district in this respect is the natural constraints set forth by the physiography and the lack of suitable locations and sufficient areal size for new construction or reserve areas in terms of disaster.

As a result, the natural thresholds of the district prevent and limit the horizontal growth and development of the urban macroform. Accordingly, the building stock can be renewed by determining new construction conditions through planning within the scope of urban transformation in the built-up area. For this settlement where disaster and other urban risks are high, avoidance planning should be made and risk mitigation measures should be taken in the plans.

Within the scope of the research, land use suitability of the district in terms of other land uses was determined. Accordingly, 70% of the area is olive grove, absolute agricultural area, agriculture, forest and protected areas. According to sustainability and nature conservation criteria, the current use of these areas should be preserved and maintained.

Areas with absolute agricultural performance in terms of suitability for agriculture should never be used for purposes other than agricultural activities. Soils with high agricultural productivity and biomass production capability should be declared as absolute agricultural areas and should not be used for non-agricultural purposes.

In order to create sustainable, safe, livable, disaster prepared and resilient living environments, methods and approaches that take disaster hazards and risks into account should be integrated with the planning system and construction process. It is aimed to identify hazard and risk sources in settlements, to obtain input data, to determine hazards at country, regional and urban scales, to define, analyse and zone risks (Kentleşme Şûrası, 2018).

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REFERENCES

Afet İşleri Genel Müdürlüğü. (2006). *Guide for the integration of geoscientific data into planning [Yer bilimsel verilerin planlamaya entegrasyon klavuzu]*. Retrieved Jan 14, 2025, from https://www.afad.gov.tr/kurumlar/afad.gov.tr

Afet ve Acil Durum Yönetimi Başkanlığı. (2023). *Provincial disaster risk reduction plan guide AFAD. [İl afet risk azaltma planı kılavuzu AFAD]*. Retrieved Jan 14, 2025, from https://www.afad.gov.tr

Bilgin, İ. (1967). *Geographical study of the Samanlı Mountains [Samanlı Dağları coğrafi etüdü]*. İstanbul Üniversitesi Edebiyat Fakültesi Yayınları

Dereköy, Ö. F. (2006). *Petrographic and petrological study of the Fıstıklı granite, Armutlu Peninsula [Armutlu Yarımadası, Fıstıklı granitinin petrografik ve petrolojik incelemesi] [Unpublished master's thesis]*, İstanbul Teknik Üniversitesi.

Dönmez, Y. (1985). *Plant geography [Bitki coğrafyası]*. İstanbul Üniversitesi Edebiyat Fakültesi Yayınları.

Emre, Ö. (1999). *Land use potential of Yalova and its surroundings and possible settlement areas after the August 17, 1999 earthquake [Yalova ve Çevresinin Arazi Kullanım Potansiyeli ve 17 Ağustos 1999 Depremi Sonrasında Olası Yerleşme Alanları]*. Maden Tetkik Arama Genel Müdürlüğü.

European Landscape Convention. (2004). *Council of Europe Landscape Convention ELC, (European Landscape Convention No. 176)*. Retrieved Jan 14, 2025, from https://www.coe.int/en/web/landscape

Forman, R. T. T. (2008). *Urban regions: Ecology and planning beyond the city*. Cambridge University Press. https://doi.org/10.1017/CBO9780511754982

Gazioğlu, C., Yücel, Z. Y. & Doğan, E. (2005). Morphological features of major submarine landslides of Marmara Sea using multibeam data. *Journal of Coastal Research*, *21*(4), 664–673. https://doi.org/10.2112/03-0060.1

İl Planlama ve Risk Azaltma Daire Başkanlığı. (2020). *Provincial Disaster Risk Reduction Plan Preparation Guide IRAP [İl Afet Risk Azaltma Planı Hazırlama Kılavuzu İRAP]*. Retrieved Jan 14, 2025, from https://irap.afad.gov.tr/upload/Node/42062/files/

İstanbul Büyükşehir Belediyesi. (2002). *Republic of Turkey Istanbul Province basic disaster prevention/mitigation plan study including seismic microzonation, Final main report, Volume V [Türkiye Cumhuriyeti İstanbul İli sismik mikrobölgeleme dahil afet önleme/*

azaltma temel planı çalışması, Sonuç ana rapor, Cilt V]. Pacific Consultants International, OYO Corporation, Japon Uluslararası İşbirliği Ajansı JICA ve İstanbul Büyükşehir Belediyesi İBB. Retrieved Jan 14, 2025, from https://depremzemin.ibb.istanbul/uploads/prefix-jica-turkce-raporu-66a39c6e9b70d.pdf

İstanbul Valiliği. (2014). *Istanbul Seismic Risk Mitigation and Emergency Preparedness Project ISMEP [İstanbul sismik riskin azaltılması ve acil durum hazırlık projesi İSMEP]*. İstanbul Proje Koordinasyon Birimi.

Japon Uluslararası İşbirliği Ajansı, (2004). *National strategy report on natural disasters in Türkiye [Türkiye'de doğal afetler konulu ülke strateji raporu]*. JICA.

Koç, G. (2007). *Assessment of the liquefaction potential of Gölcük and its surroundings [Gölcük ve çevresinin sıvılaşma potansiyelinin değerlendirilmesi]* [Unpublished master's thesis]. Kocaeli Üniversitesi.

Land Monitoring Service, (2018). *Corine Land Cover*. Retrieved Jan 14, 2025, from https://land.copernicus.eu/en/products/corine-land-cover

Maden Tetkik Araştırma Müdürlüğü (MTA). (2019). *Mineral Research and Exploration Reports [Maden Tetkik Araştırma Raporları]* . Retrieved Jan 14, 2025, from https://www.mta.gov.tr

Ndubisi, F. (2002). *Ecological planning: A historical and comparative synthesis*. Johns Hopkins University Press.

Ndubisi, F. O. (2014). *The ecological design and planning reader*. Island Press. https://doi.org/10.5822/978-1-61091-491-8

Özdemir, M. A. & Bahadır, M (2008b). *Temporal change in land use in the Armutlu Peninsula [Armutlu Yarımadası'nda Arazi Kullanımının Zamansal Değişimi]*. 2nd Remote Sensing and Geographic Information Systems Symposium. UZAL-CBS, 13–15 Oct 2008, Erciyes University, Kayseri, pp. 455–467. Retrieved Jan 14, 2025, from http://uzalcbs.org/wp-content/

Özdemir, M. A. & Bahadır, M. (2008a). Temporal change in land use in the Armutlu Peninsula (1992–2007) [Armutlu Yarımadası'nda arazi kullanımının zamansal değişimi (1992–2007)]. *Geogr J, 17,* 1–15.

Özmen, M. (2000). *Damage Status of the Izmit Gulf Earthquake on August 17, 1999*. Turkish Earthquake Foundation, Earthquake Report. TDV / DR 010-53.

Sancaklı, N. (2004). *Earthquakes in the Marmara Region (427 BC–1912 AD): Tsunamis in the Marmara Sea.* Kastaş Publications.

T.C. Resmî Gazete, (2012). *Regulation on the Preparation, Implementation and Monitoring of Basin Management Plans (Regulation No: 28444) [Havza Yönetim Planlarının Hazırlanması, Uygulanması ve Takibi Yönetmeliği]*. No: 28444.

T.C. Resmi Gazete. (2005). *Soil Conservation and Land Use Law (Law No. 5403) [Toprak koruma ve arazi kullanımı kanunu*. No. 5403.

T.C. Resmî Gazete. (2007). *Regulation on Structures to Be Built in Disaster Areas (Law No. 7269) [Afet bölgelerinde yapılacak yapılar hakkında yönetmelik]*. No. 7269

T.C. Resmî Gazete. (2014). *Regulation on Spatial Plans, Regulation on the Preparation of Spatial Plans (Regulation No. 29030) [Mekânsal Planlar Yönetmeliği, Mekânsal Planlar Yapım Yönetmeliği (Yönetmelik No. 29030)]*. No. 29030

T.C. Resmi Gazete. (2016). *Regulation on Flood Risk Management Plans (Regulation No. 29170) [Taşkın riski yönetim planları yönetmeliği]*. No. 29170.

T.C. Resmi Gazete. (2017). *Regulation on the Protection, Use, and Planning of Agricultural Lands (Regulation No. 30265) [Tarım arazilerini koruma, kullanma, planlanma yönetmeliği]*. No. 30265.

T.C. Resmi Gazete. (2021). *Law on Protection Against Floods and Inundations (Law No. 4373) [Taşkın ve su baskınlarına karşı korunma kanunu]*. No. 4373.

Tozar, T. (2006). *Ecological planning methods developed for the sustainability of natural resources [Unpublished master's thesis]*. Yıldız Teknik Üniversitesi.

Urbanization Council. (2018). *Urbanization Council [Kentleşme Şûrası]*. Uluslararası Kentleşme ve Çevre Şurası Sempozyumu, Bildiri Kitabı 4, pp 4–18. 28–29 January 2018, Balıkesir. Retrieved Jan 14, 2025, from https://sehirciliksurasi.csb.gov.tr/

Uzun, O. F., İlke, E. F., Çetinkaya, G., Erduran, F. & Açıkgöz, S. (2012). *Konya Province Bozkır-Seydişehir-Ahırlı-Yalıhüyük districts and Suğla Lake landscape management, conservation and planning project [Konya ili Bozkır-Seydişehir-Ahırlı-Yalıhüyük ilçeleri ve Suğla Gölü peyzaj yönetimi koruma ve planlama projesi]*. T.C. Orman ve Su İşleri Bakanlığı, Doğa Koruma ve Milli Parklar Genel Müdürlüğü.

Water Directive, (2007). *European Union Water Environment Directive: European Water Resilience Strategy* (2007/60/EC). Retrieved Jan 14, 2025, from https://www.eea.europa.eu/themes/water

Yalova Governorship. (2024). *Çınarcık district location information*. Retrieved Jan 14, 2025, from http://www.yalova.gov.tr/cinarcik

Yalova Multicipality. (2024). *Çınarcık district general information*. Retrieved Jan 14, 2025, from https://www.cinarcik.bel.tr/tr

Yılmaz, D., Köprübaşı, N., Çelebi, D. & Köprübaşı, N. (2010). Geochemical characteristics of the Esenköy (Çınarcık-Yalova) granitoid [Esenköy (Çınarcık-Yalova) granitoyidinin jeokimyasal özellikleri]. *Journal of Applied Earth Sciences, 9*(2), 19–37.

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Article

A field-based methodology for thermal comfort evaluation: A case study on university classrooms

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ABSTRACT

Ensuring thermally comfortable indoor environments is essential for occupant well-being, learning performance, and energy efficiency. This study proposes a field-based methodology for the assessment of thermal comfort, aligned with international standards and designed to be reproducible and applicable across diverse building types and climatic conditions. The objective methodology integrates both objective (measurements) and subjective (surveys) methods, combined with behavioral observations, to provide a detailed assessment of indoor thermal comfort conditions. The methodology integrates long-term and short-term measurements of air temperature, mean radiant temperature, relative humidity, air velocity, and along with the calculation of PMV/PPD. The data reliability is verified through calibration, inter-device agreement, and statistical evaluation using Mean Bias Error (MBE) and coefficient of determination (R^2). Furthermore, occupant surveys and camera-based observations capture subjective perceptions and adaptive behaviors, linking measured values with real-world occupancy conditions. The proposed methodology was applied to three amphitheater-style university classrooms characterized by high window-to-wall ratios on the south-facing façade. Findings showed that thermal gradients near south windows, confirmed by surveys reporting higher dissatisfaction and reduced concentration in south façade-adjacent zones. Observations revealed limited adaptation, with windows seldom opened and curtains generally closed, and underscoring results indicated the need for passive or automated strategies. The results confirm the methodology's ability to capture spatial and temporal variations, link predictive indices to occupant perception. Overall, the study offers a standards-based methodology suitable for assessing thermal comfort in different building type and climate.

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INTRODUCTION

Thermal comfort is a well-established research focus in building science, not only due to its impact on occupant, well-being, health, cognitive performance, and productivity but also because of the increasing demand for energy efficient and climate-resilient building design (Hong et al., 2023). Recent research has increasingly emphasized occupant-centered assessment methods, integrating in-situ measurements, behavioral observations, and data-driven modeling to capture the complexity of real indoor environments (Kim, Schiavon, & Brager, 2018). Despite these advances, there is still a need for field-based methodologies that are simultaneously comply with standards, reproducible, and broadly applicable, thereby enabling reliable cross-study comparisons and supporting evidence-based design decisions across diverse building types and climatic conditions. In this context, adaptive comfort theory has provided an important counterpoint to classical laboratory-based models by recognizing the dynamic role of climate, culture, and behavioral adaptation in shaping thermal expectations (Brager & de Dear, 2001; Nicol & Humphreys, 2002).

Classical approaches such as the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) models, introduced by Fanger and embedded in standards such as ASHRAE Standard 55 and ISO 7730 remain the dominant frameworks for quantifying thermal comfort (de Dear & Brager, 1998; ISO, 2025; ASHRAE, 2023). However, these models have been validated extensively in controlled laboratory settings, their direct application to real environments often encounters difficulties due to spatial non-uniformities, transient thermal condition dynamics, and variable occupant behavior. This limitation has led scholars to argue for the integration of adaptive opportunities, such as operable windows, shading, and occupant control, into predictive frameworks, since users often tolerate wider ranges of indoor conditions when provided with environmental control (Humphreys & Nicol, 2002; Schweiker & Wagner, 2016).

Recent studies have attempted to address these limitations through hybrid and adaptive strategies. For example, Kim et al. (2018) demonstrated that personalized comfort models calibrated with human-centric parameters can improve prediction accuracy in real buildings. Comparative analyses of thermal indices such as SET, UTCI, and PET have also been carried out to evaluate robustness under different environmental and cultural contexts (Jing et al., 2024). Parallel research has also examined the links between thermal comfort and other dimensions of indoor environmental quality, including daylighting and acoustics, highlighting the importance of multi-criteria frameworks (Dawe et al., 2021; Tzempelikos & Athienitis, 2007). Yet, many of these efforts remain confined to idealized test scenarios or single-case studies, restricting their generalizability.

There remains to be a need for methodologies that can be applied under real-world conditions and enable systematic comparison of indoor spaces with varying physical characteristics. Recent studies support this direction: Sun et al. (2022) proposed a portable and reproducible framework for long-term thermal comfort evaluation using a standardized data model, while Dawe et al. (2021) reported field-based evaluations of thermal and acoustic comfort in office buildings, underscoring the value of in-situ assessments. However, existing studies either propose generalized frameworks without testing in uniform buildings or examine building types with limited spatial variability, leaving a gap for methods that can compare comfort conditions across spaces with different geometries and façade features within the same building type.

Bay Şahin and Elnimeiri (2025) identified severe thermal discomfort in upper-level social housing units in hot-dry climates, primarily using diagnostic imaging and surveys. Similarly, Şuta and Zencirkıran (2024) explored occupant satisfaction in mass housing during the COVID-19 period, emphasizing the importance of indoor environmental quality but without offering a standardized measurement framework. These contributions underline the importance of empirical research in uncovering comfort-related issues in real buildings. Collectively, these studies confirm the importance of empirical field research while also exposing the absence of a coherent, widely applicable methodology for thermal comfort evaluation. Such a methodology would enable consistent comparison of results across different climate, buildings and rooms and research contexts.

To address this gap, the present research introduces a reproducible, standards-aligned, field-based methodology specifically designed for assessing indoor thermal comfort conditions under in real word building environments. The methodology integrates both objective and subjective methods, combined with behavioral observations, to provide a detailed assessment of indoor thermal comfort conditions. The methodology is aligned with international standards (ISO 7730, ASHRAE 55) and designed to be reproducible and broadly applicable. It combines long-term and short-term measurement of environmental parameters—air temperature, mean radiant temperature, relative humidity, air velocity, and PMV/PPD—with personal factors -clothing insulation and activity level. Measurement reliability is ensured through systematic device calibration, inter-device comparison, and statistical validation using Mean Bias Error (MBE) and coefficient of determination (R^2), consistent with ASHRAE Standard 14 (ASHRAE, 2023). A substantial body of research has investigated thermal comfort in educational and office environments through field measurements and simulation-based analyses; however, the majority of these studies have tended to rely exclusively on either objective environmental data or subjective comfort assessments, limiting methodological integration.

This limitation often prevents a full understanding of how occupants dynamically interact with their environments under real-world conditions. Mıhlayanlar et al. (2017) investigated thermal comfort in a higher education facility in Edirne using on-site environmental measurements. In such field studies, however, integrating information on occupant behavior and adaptive responses is also essential for interpreting comfort conditions more comprehensively. De Dear and Brager (1998) advanced the adaptive comfort framework through large-scale survey data across diverse climates, while Yao et al. (2009) and Fanger (1970) focused primarily on quantitative comfort indices, placing limited emphasis on contextual or behavioral adaptation. Although these contributions have greatly advanced the understanding of indoor environmental quality, the lack of integration between objective field measurements, subjective thermal sensation surveys, and behavioral observations still constrains the holistic interpretation of comfort in real-world settings. Therefore, this study aims to address this methodological gap by developing a comprehensive field-based evaluation framework that simultaneously captures measured environmental variables, subjective responses, and observed adaptive behaviors under actual classroom occupancy conditions to provide a more holistic interpretation of thermal comfort assessments.

Following its development, the methodology was applied in three amphitheater-style university classrooms with high window-to-wall ratios and varying façade orientations. This application enabled the identification of spatial thermal gradients, localized discomfort zones, and orientation-dependent thermal dynamics. Rather than solely reporting case-specific findings, the study demonstrates that the proposed methodology provides a reliable, generalizable framework for evaluating thermal comfort in educational buildings.

METHODOLOGY

This study develops a field-based methodology (Figure 1) for evaluating indoor thermal comfort conditions of any building type. The methodology is designed to be applied in different climates and building types, ensuring both comparability and applicability. It integrates objective (measurements) methods, subjective (surveys) methods, and behavioral observations to enable systematic assessment of thermal comfort conditions.

Before initiating data collection, the methodology prescribes a preliminary data collection phase to establish a reliable baseline for subsequent thermal comfort evaluation.

As a first step, architectural, technical references, including architectural drawings, and façade details, should be reviewed to define the geometry, constructional characteristics and environmental control systems. This reference information is then supplemented by on-site verification and measurement of:

- Spatial characteristics: Room dimension and layout, environmental control systems and constructional element thicknesses.
- Building envelope properties: Optical and thermophysical properties and fenestration parameters (U-values of interior and exterior walls and windows etc.).
- Environmental Control systems (Mechanical and Electrical) Systems: Heating, ventilation, and air-conditioning (HVAC) systems.

Simultaneously, outdoor climatic conditions are obtained from meteorological data and on-site reference measurements to establish contextual boundary conditions.

These factors should be systematically documented because they directly influence thermal comfort assessments. In parallel, outdoor environmental conditions are determined using meteorological data, and measurements.

Objective (Measurements) Method for Thermal Comfort Assessment

Thermal comfort is influenced by both objective and subjective parameters. Subjective parameters, which pertain to the individual characteristics of the human body, therefore vary from person to person. Consequently, thermal comfort assessments are typically based on objective parameters, which can be categorized into personal and environmental factors.

- Personal Thermal Comfort Factors: It is suggested that, clothing insulation (clo) is periodically updated to reflect seasonal variations. Determining instantaneous clothing insulation levels by surveys and entering them into the calculation of PMV produces more accurate assessments (Zoroğlu and Gedik, 2022). Activity levels are determined by observing general student behaviors and aligning them with these standards-based values (Zhang et al., 2020).
- Environmental Thermal Comfort Factors: Air temperature, mean radiant temperature, relative humidity, and air velocity are measured continuously and periodically.
- Thermal Comfort Indices: Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) are calculated using measured environmental data and personal parameters obtained from standards and surveys.

The objective methodology is aligned with ISO 7730 and ASHRAE Standard 55, ensuring compliance with internationally recognized protocols. Measurement points are selected to represent critical locations within the room, particularly areas close to windows or other potential dis-

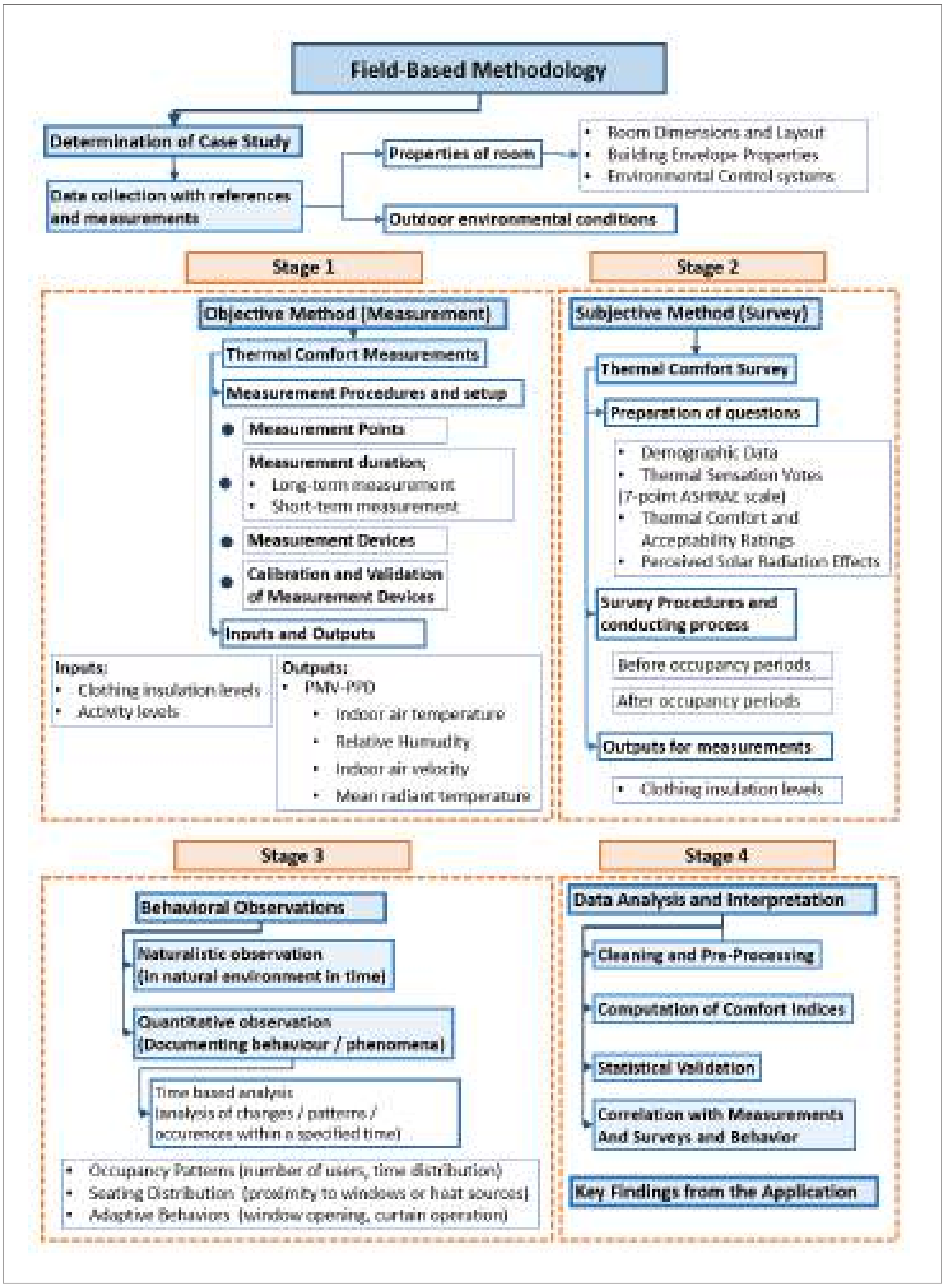


Figure 1. The field-based methodology for thermal comfort evaluation.

comfort zones, and are compared with reference points away from these zones. As suggsted relevant standards, air temperature and air velocity are measured at 0.1 m, 0.6 m, and 1.1 m heights, while humidity and mean radiant temperature are measured at 0.6 m to reflect seated occupant conditions.

Indoor thermal comfort measurements are conducted using calibrated thermal comfort measurement devices (e.g., Delta Ohm HD 32.3A, Testo 480), capable of calculating PMV/PPD. Long-Term measurements are performed with permanently installed devices, enabling continuous monitoring over representative periods. Short-Term measurements are conducted at selected intervals to capture real-time variations and transient conditions.

Measurement methodology of this study suggests that ensuring data integrity, so protective enclosures and uninterruptible power supplies (UPS) are used to prevent data loss and safeguard equipment from environmental disturbances.

Verification of thermal comfort measurement devices;

- Determination the relationship between devices: Comparison of measurement device results with each other (fixed measurements in a laboratory environment)
- Determination the protective enclosures effect: Comparison of devices within and without protective enclosures in real-word conditions
- Prior to field installation, all devices undergo laboratory calibration and inter-device comparison. Reliability is quantified using Mean Bias Error (MBE) and coefficient of determination (R^2) for key parameters (like air temperature, globe temperature, PMV). The methodology requires that MBE values remain within the ±10% acceptability range specified by ASHRAE Standard 14, so that measurements remain consistent across rooms. Additionally, R^2 values close to 1 show strong consistency between measurements.

Subjective (Survey) Method for Thermal Comfort Assessment

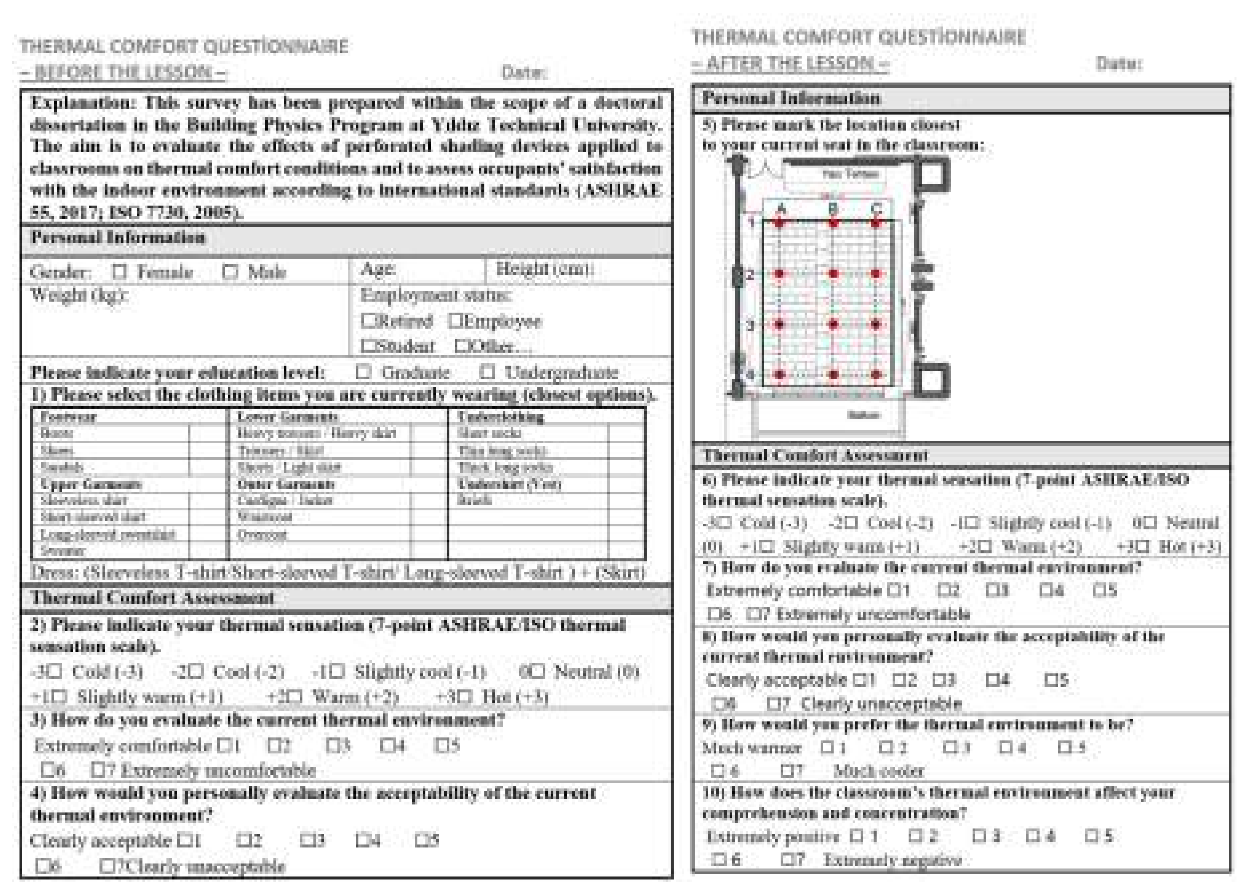
Thermal comfort surveys were administered before and after lesson, in accordance with ISO 10551:2019. Using a standards-based questionnaire not only enhances comparability across studies but also provides a consistent framework for interpreting subjective responses. The surveys applied in this study collect both subjective and objective parameters influencing thermal comfort (Figure 2):

- Demographic Data (age, gender, clothing insulation)
- Thermal Sensation Votes (7-point ASHRAE scale)
- Thermal Comfort and Acceptability Ratings
- Thermal preference and perceived impact on comprehension

This two-phase approach captures temporal variations in thermal perception and enables direct comparison between measured PMV and Actual Mean Vote (AMV). Clothing insulation (clo) values are collected through occupant surveys and periodically updated in PMV calculations to reflect seasonal changes.

Behavioral Observations for Thermal Comfort Assessment

Camera recordings and structured field notes are employed to record occupancy, seating distribution, and adaptive behaviors. These datasets are synchronized with measurement intervals, providing a holistic understanding of how


THERMAL COMFORT QUESTIONNAIRE
– BEFORE THE LESSON – Date:

Explanation: This survey has been prepared within the scope of a doctoral dissertation in the Building Physics Program at Yıldız Technical University. The aim is to evaluate the effects of perforated shading devices applied to classrooms on thermal comfort conditions and to assess occupants' satisfaction with the indoor environment according to international standards (ASHRAE 55, 2017; ISO 7730, 2005).

Personal Information

Gender: ☐ Female ☐ Male | Age: | Height (cm):
Weight (kg): | Employment status: ☐Retired ☐Employee ☐Student ☐Other…

Please indicate your education level: ☐ Graduate ☐ Undergraduate

1) Please select the clothing items you are currently wearing (closest options).

Footwear		Lower Garments		Underclothing	
Boots		Heavy trousers / Heavy skirt		Short socks	
Shoes		Trousers / Skirt		Thin long socks	
Sandals		Shorts / Light skirt		Thick long socks	
Upper Garments		**Outer Garments**		**Undershirt (Vest)**	
Sleeveless shirt		Cardigan / Jacket		Briefs	
Short-sleeved shirt		Waistcoat			
Long-sleeved sweatshirt		Overcoat			
Sweater					

Dress: (Sleeveless T-shirt/Short-sleeved T-shirt/ Long-sleeved T-shirt) + (Skirt)

Thermal Comfort Assessment

2) Please indicate your thermal sensation (7-point ASHRAE/ISO thermal sensation scale).
-3☐ Cold (-3) -2☐ Cool (-2) -1☐ Slightly cool (-1) 0☐ Neutral (0) +1☐ Slightly warm (+1) +2☐ Warm (+2) +3☐ Hot (+3)

3) How do you evaluate the current thermal environment?
Extremely comfortable ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Extremely uncomfortable

4) How would you personally evaluate the acceptability of the current thermal environment?
Clearly acceptable ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7Clearly unacceptable

THERMAL COMFORT QUESTIONNAIRE
– AFTER THE LESSON – Date:

Personal Information

5) Please mark the location closest to your current seat in the classroom:

Thermal Comfort Assessment

6) Please indicate your thermal sensation (7-point ASHRAE/ISO thermal sensation scale).
-3☐ Cold (-3) -2☐ Cool (-2) -1☐ Slightly cool (-1) 0☐ Neutral (0) +1☐ Slightly warm (+1) +2☐ Warm (+2) +3☐ Hot (+3)

7) How do you evaluate the current thermal environment?
Extremely comfortable ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Extremely uncomfortable

8) How would you personally evaluate the acceptability of the current thermal environment?
Clearly acceptable ☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 Clearly unacceptable

9) How would you prefer the thermal environment to be?
Much warmer ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐7 Much cooler

10) How does the classroom's thermal environment affect your comprehension and concentration?
Extremely positive ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐7 Extremely negative

Figure 2. Thermal comfort survey (questions) conducted before and after occupancy periods.

occupant actions interact with thermal comfort conditions. Observations include:

- Occupancy (number and positions of users, time distribution)
- Seating Distribution (proximity to windows or heat sources)
- Adaptive Behaviors (window opening, curtain operation)

Data Analysis and Interpretation

The final step of the methodology involves a combined evaluation of measurements, surveys, and behavioral observations. PMV values obtained from measurements are systematically compared with AMV derived from surveys, allowing the validation of measured results against occupant perception. To ensure reliability, the methodology emphasizes the synchronized collection of measurements and surveys, allowing occupant perception to be directly linked to the recorded indoor thermal comfort conditions. Behavioral data, including occupancy and window/curtain operation, are synchronized with measurement periods to contextualize variations in thermal comfort conditions.

The methodology prescribes a structured approach to data analysis:

- Data pre-processing: Removal of incomplete or erroneous readings.
- Computation of Comfort Indices: Calculation of PMV, AMV and relevant indices.
- Statistical Validation: Inter-device and inter-room comparison using MBE, R^2, and regression analyses, relationship between classrooms etc.
- Correlation with Measurements and Surveys and Behavior: Linking measured indices with AMV, APD, and behavioral patterns and identifying localized discomfort and validate model predictions.

This methodology provides a reliable and generalizable framework for thermal comfort evaluation, while the integrated analysis ensures a detailed assessment of room performance, orientation effects, and the identification of spatial discomfort.

APPLICATION OF THE METHODOLOGY

Following the development of the methodology, it was systematically implemented in three amphitheater-style classrooms at Yıldız Technical University's Beşiktaş Campus (B-501, B-502, B-503), each characterized by high window-to-wall ratios and distinct façade orientations (south, southeast, southwest). The aim was to demonstrate the reproducibility of the method, identify spatial discomfort zones, and validate the integration of objective, subjective, and behavioral data under real word conditions.

The selection process prioritized classrooms with high solar exposure and expected non-uniform thermal comfort conditions. Architectural drawings were reviewed to determine room dimensions, seating arrangements, and façade configurations, which were subsequently verified through on-site measurements.

The amphitheater form of classrooms (Figure 3) and thermophysical principles—where heated air rises and accumulates near windows—further intensified discomfort in façade-adjacent areas, particularly during periods of occupancy. The physical characteristics of the classrooms are summarized in Table 1 and Table 2 presents the window-to-wall ratios (WWR).

Building envelope properties (section layers, materials, and U-values) were determined using the TESTO 635 humidi-

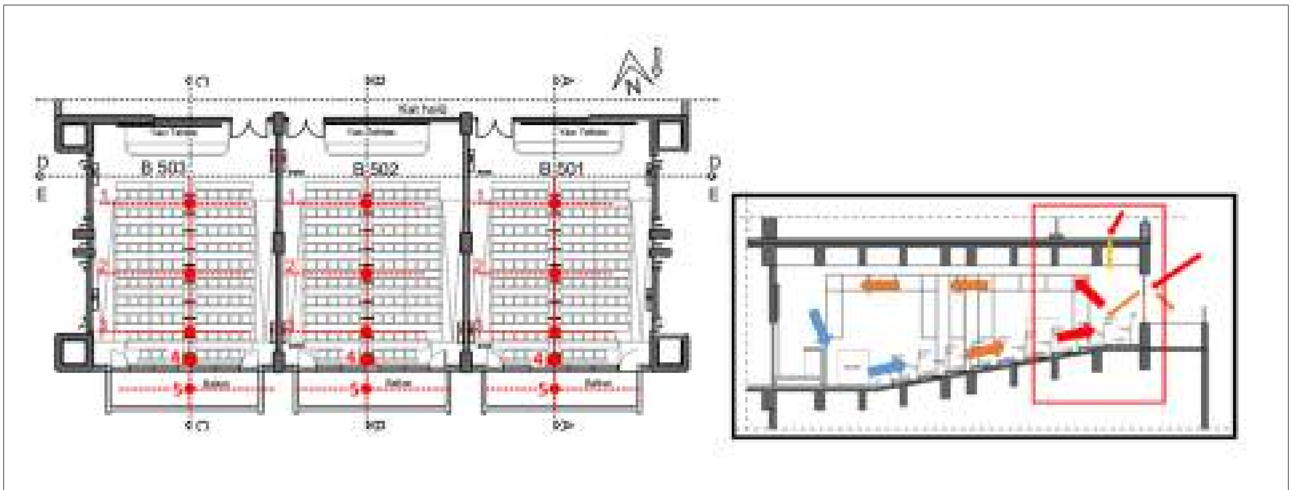


Figure 3. Thermal Comfort Measurement Points in Classrooms (Points 1, 2, and 3 for short-term measurements, and Point 4 for fixed measurements, Point 5 for outdoor weather conditions measurement) and Sections of Classroom B-501.

Table 1. Physical characteristics of classrooms.

Classrooms	Direction of classroom	Dimensions (amphitheater)	Heating system and number of Radiator	Capacity (person)
B 501	South-East	11.76×9.08×(2.7-3.80)	Gas central heating systems, Cast iron radiator- 4 radiators	109
B 502	South	11.76×8.90×(2.7-3.80)	Gas central heating systems, Cast iron radiator- 3 radiators	109
B 503	South-West	11.76×9.08×(2.7-3.80)	Gas central heating systems, Cast iron radiator- 4 radiators	109

Table 2. Current transparency ratios of rooms.

Room	Direction of Classroom	Capacity (person)	Dimension of Classroom	Direction of transparent component	Transparency Ratio (WWR – Window to Wall Ratio)		
					East	South	West
B 501	South-East	109	11.76x9.08×(2.7-3.80)	**South and East**	11.5%	60%	-
B502	South	109	11.76×8.90×(2.7-3.80)	**South**	-	60%	-
B503	South-West	109	11.76×9.08×(2.7-3.80)	**South and West**	-	60%	11.5%

ty and architectural documentation. Classrooms equipped with mechanical heating and natural ventilation were intentionally selected to allow diverse evaluations of thermal comfort. Table 3 details the building envelope section layers and associated U-values derived from field measurements and project drawings.

The methodology was tested between 3 and 19 November through long-term measurements, while short-term measurements and occupant surveys were simultaneously conducted on 17 November. Outdoor climatic conditions were recorded at a designated reference point 5 (Figure 3), and the results are presented in Table 4.

Application of Objective (Measurements) Method

The first stage of the application involved defining measurement points within the selected rooms. These points were chosen strategically to capture the spatial variability of thermal comfort conditions, with one point always located near the south-facing window to record the influence of solar exposure. Four points per classroom were selected, including points near the south-facing windows and reference points farther away, to capture spatial gradients. In each classroom, three points were determined for short-term measurements, while one fixed point was chosen for continuous long-term monitoring (4. point) (Figure 3).

The Delta Ohm HD 32.3A Microclimate Analyzer and Testo 480 were employed to record air temperature, mean radiant temperature, relative humidity, and air velocity. Clothing insulation and activity level (Table 5) were integrated into the devices, enabling calculation of PMV and PPD. Thermal comfort assessment was conducted in accordance with ISO 7730 and ASHRAE Standard 55.

Following the selection of measurement points, measurement devices and periods, three Delta Ohm HD 32.3A microclimate analyzers were permanently installed near the windows to collect long-term data, while a fourth device was used to perform short-term measurements at other points. Protective enclosures and UPS systems (Figure 4) were used to safeguard devices and prevent data loss due to power fluctuations.

Prior to field study, all devices underwent laboratory calibration and inter-device comparison. The statistical analysis revealed Mean Bias Error (MBE) values of +0.034 between Device 1 and 2, +0.064 between Device 1 and 3, and +0.030 between Device 2 and 3, all of which remained within the acceptable ±10% threshold. The corresponding coefficients of determination (R^2=0.959, 0.919, and 0.916, respectively) indicated strong correlations across devices. These results confirmed the reliability of the measurement devices (Figure 5) and validated the data quality and comparability across classrooms.

The effect of protective enclosures was evaluated under real-word conditions. Verification results demonstrated that the enclosures did not significantly affect measurement accuracy, with MBE in PMV, and PPD remaining within the ±10% range (Table 6). These outcomes validated the suitability of the experimental setup for long-term monitoring and confirmed that the collected data can be considered reliable.

Application of Subjective (Surveys) Method

The thermal comfort surveys were administered immediately before and after lessons, in accordance with ISO 10551:2019, in order to capture temporal changes in thermal perception.

Table 3. Building envelope section layers according to architectural drawings and U values from measurements.

Building envelope Components	Measurement U-Value (W/m2K)	Section Layers (Project)	
		Material	Thickness (m)
Exterior Wall	0.387	Plaster	0.02
		Heraklith	0.03
		Exposed Concrete	0.15
Internal Wall	0.732	Perforated Particleboard	0.025
		Exposed Concrete	0.05
		Bakelite Glass Wool	0.05
		Perforated Particleboard	0.025
Ceiling-Floor	-	Rubber Floor Covering	0.05
		Alum	0.025
		Leveling Concrete	0.04
		Reinforced Concrete Floor	0.1
Terrace Roof	-	Tile Mosaic	0.025
		Mortar	0.025
		Ruberoid and Water Insulation(3 layers)	-
		Polyurethane heat insulation	0.05
		Vapor Insulation	-
		Slope concrete	0.03 – 0.24
		Reinforced Concrete Floor	0.1
Window	1.847	-	-
Door	1.5	-	-

In addition to demographic data such as age, gender, and clothing insulation levels, the questionnaires included thermal sensation votes with seven-point scale, thermal comfort and acceptability ratings, and thermal preference, and perceived influence on comprehension and concentration. This design enabled a direct comparison between the measured PMV and the AMV derived from occupant responses. Surveys were conducted simultaneously with short-term measurements on 17 November 2021, involving 24 participants.

Application of Behavioral Observation

Behavioral observations were conducted through a camera recording system installed in each classroom (Figure 6; Figure 7). The recordings were analyzed to determine occupancy levels, seating distribution, and adaptive behaviors such as window and curtain operation. These observations were synchronized with the measurement periods, providing a comprehensive interpretation of occupant behavior in relation to thermal comfort conditions.

RESULTS

The systematic implementation of the proposed methodology enabled the identification of spatial thermal gradients, localized discomfort zones, and the correspondence between occupant perception and measured thermal indices.

Data Analysis, Validation and CrossRoom Comparison

The data analysis process was conducted in two distinct stages. The first stage comprised preliminary verification analyses carried out prior to field study, including device calibration, inter-device comparison, and the evaluation of protective enclosures. These assessments, presented in the methodology section, confirmed negligible differences between de-

Table 4. The outdoor climate conditions during short-term field study.

Date	Time	Mean Radiant Temperature (C°)	Air Temperature (C°)	Relative Humidity, RH (%)	Air Velocity, Va (m/s)	Sky Condition
17.11.2021	14:17	20.7	18.8	45.2	0.53	Overcast

Table 5. Field study measurement Parameters.

Measurement points	Measurement Height	Measurement type-time and interval	Activity Level	Clothing insulation level
4 points for each classroom	0.6 meters	According to Time - Short-term (15 min) and long-term measurements Both: 30 sec. intervals	1.2 met	Be determine depending on periods (0.8 clo, in this field study)

Note: Devices were acclimatized for 15 minutes before measurements.

Table 6. The mean values and standard deviations of the measurement results obtained under both protected and unprotected conditions for the 1. device.

		Tg (C°)	Ta (C°)	RH (%)	Va (m/s)	PMV	PPD (%)
Protected	Mean	34.20	33.41	46.50	0.009	2.83	97.99
	Std. Dev.	0.34	0.15	0.52	0.01	0.08	0.80
Unprotected	Mean	34.74	33.76	45.93	0.018	2.96	98.90
	Std. Dev.	0.31	0.21	0.39	0.015	0.08	0.36
MBE		-1.55	-1.04	1.24	-50.0	-4.39	-0.92

Tg: Mean radiant temperature, Ta: Air temperature, RH: Relative humidity, Va: Air velocity

vices and demonstrated that Mean Bias Error (MBE) values for PMV remained within the ±10% acceptability threshold, thereby ensuring that subsequent measurements were both valid and comparable across classrooms.

The second stage focused on the systematic integration and interpretation of field data. This stage analiyzed and combined measurements, surveys, and behavioral observations to capture spatial and temporal variations in thermal comfort conditions.

Measurement Results

Field measurements revealed clear spatial and temporal variations in thermal comfort conditions across the three classrooms. Short-term measurements (Figure 8) indicated pronounced thermal gradients, with PMV values at window-adjacent points exceeding +0.5 and globe temperatures more than 2 °C higher than those recorded at central points.

The implementation of the methodology successfully identified localized discomfort zones near the south-facing façades where PMV values exceeded the recommended comfort thresholds (Figure 8). These findings confirm the dominant influence of direct solar radiation on local thermal comfort conditions. Under overcast sky conditions (17 November 2021), temperature differences between façade-adjacent and central points were smaller yet still measurable, indicating that thermal asymmetry persists even in the absence of direct sun. Furthermore, in Classroom B-502, although the air temperature and MRT at

Figure 4. Protective enclosures for thermal comfort measurement devices.

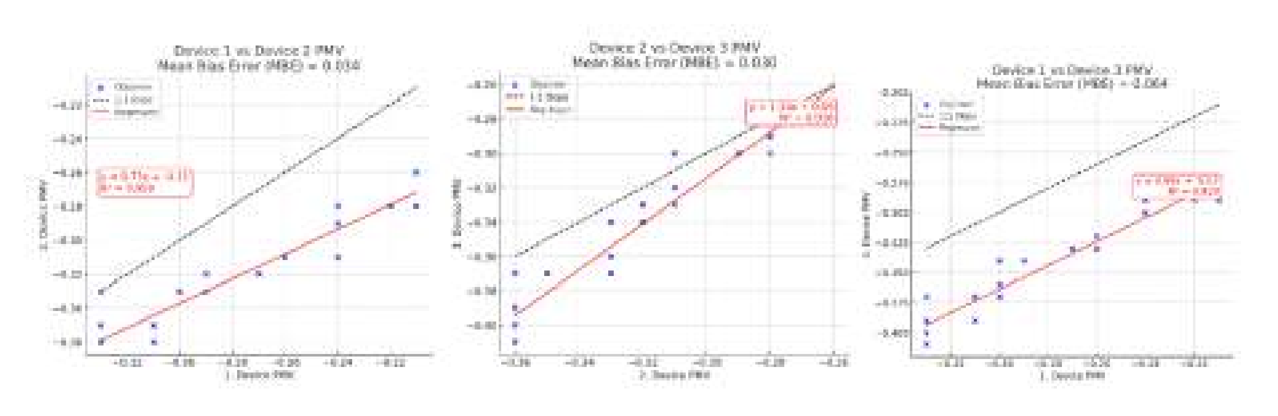


Figure 5. Verification of measurement devices (MBE and coefficient of determination (R^2) for PMV) (237 data for each device and indices-1 hour and 30 sec. intervals).

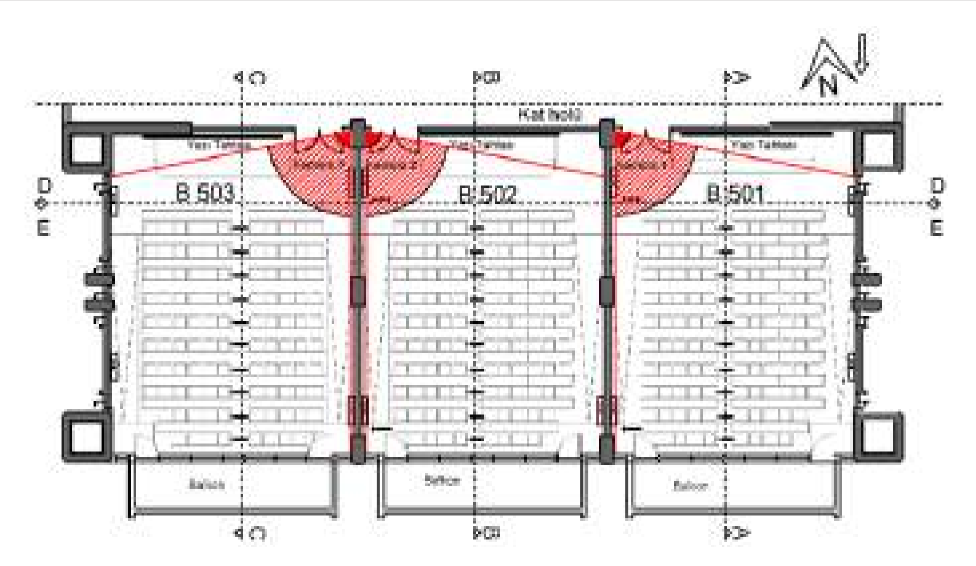


Figure 6. Camera Positions and Fields of View (Red-shaded areas indicate non-visible zones).

Point 1 were relatively higher than other points, the PMV value was observed to be lower than at the other points due to higher air velocity and lower relative humidity at this point.

Long-term monitoring was conducted between 3 and 19 November 2021, with measurements taken at 09:00, 11:00, 13:00, 15:00, and 17:00 to represent full-day conditions. The results demonstrated a consistent pattern of afternoon overheating across all classrooms (Figure 9). PMV values peaked between 13:00 and 15:00, with the most pronounced overheating observed in Classroom B-503, where PMV frequently exceeded +0.7. Classroom B-501 exhibited more pronounced morning gradients due to its east-facing façade. Relative humidity remained within the 40–60% range recommended by ASHRAE 55, and air velocity stayed below 0.05 m/s, indicating negligible effects

Figure 7. Photograph Captured from Classrooms Cameras (respectively B-501, B-502 and B-503) on 15.06.2021 at 10:00 AM.

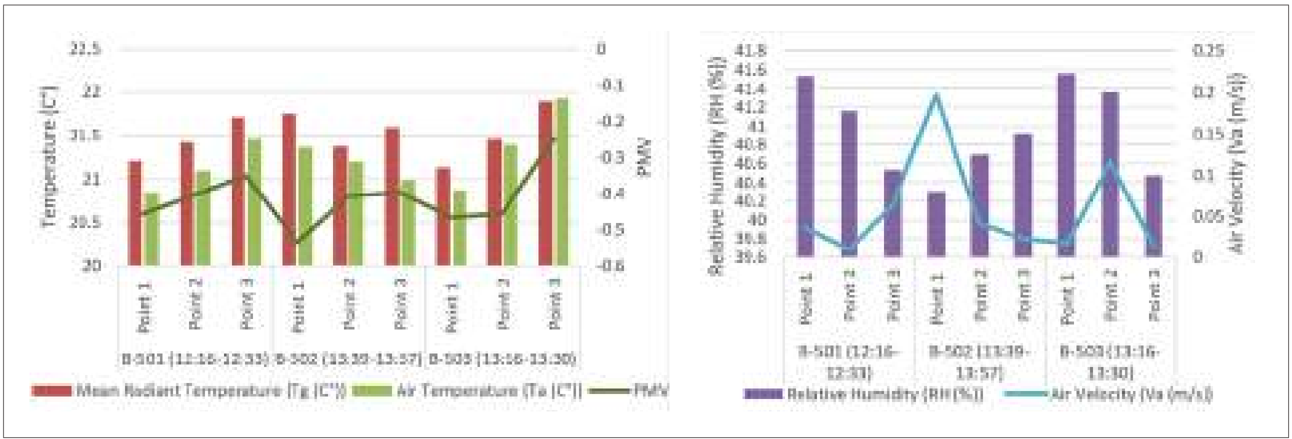


Figure 8. Short-term Measurement Results on November 17, 2021 (Mean Radiant Temperature, Air Temperature, Relative Humidity, Air velocity, and PMV).

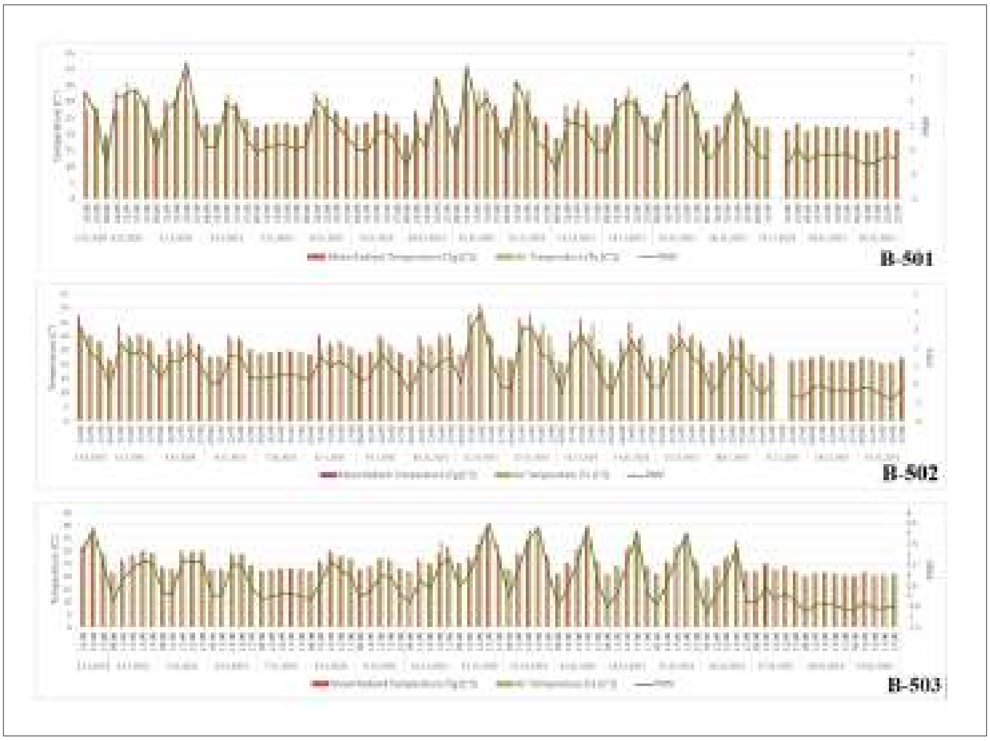


Figure 9. Long-term Measurement Results for Classroom B-501, B-502 and B-503 from November 3–19, 2021 (Mean Radiant Temperature, Air Temperature and PMV).

of natural ventilation. These results demonstrate that solar heat gains and temperature rise, rather than humidity or air movement, were the primary drivers of discomfort.

Survey Results

The thermal comfort surveys corroborated the measurement data and provided valuable insight into occupants' thermal perception. Survey results from 17 November 2021 (Table 7) show that before lesson, 50% of respondents reported "slightly warm" and 16.7% "warm," while 25% selected "neutral". Following lessons, the proportion of "slightly warm" votes decreased to 45.8%, with an increase in neutral responses (25% to 45.8%), suggesting partial adaptation and convergence toward neutrality. Despite these adaptations, more than 70% of of participants consistently rated the thermal environment as acceptable or better, although dissatisfaction was concentrated among students seated near the façades.

Thermal comfort acceptability (question 4 and 8) ratings improved after lesson, while thermal preference (question 9) responses indicated that nearly half of the students (45.8%) preferred no change, confirming that conditions were close

Table 7. Results of the thermal comfort survey conducted in classrooms on november 17, 2021 (Results are presented as percentage values (%)).

Before Lesson					.		
Question 2 (Thermal Sensation)	Hot (+3)	Warm (+2)	Slightly Warm (+1)	Neutral (± 0)	Slightly Cool (-1)	Cool (-2)	Cold (-3)
		4.2	16.7	50	25	4.2	
Question 3	Extremely Uncomfortable-1	2	3	4	5	6	Extremely Comfortable-7
			16.7	29.2	25	20.8	8.3
Question 4	Clearly Unacceptable-1	2	3	4	5	6	Clearly Acceptable-7
			12.5	16.7	16.7	33.3	20.8
After Lesson					.		
Question 6 (Thermal Sensation)	Hot (+3)	Warm (+2)	Slightly Warm (+1)	Neutral (± 0)	Slightly Cool (-1)	Cool (-2)	Cold (-3)
		4.2	16.7	45.8	25	8.3	
Question 7	Extremely Uncomfortable-1	2	3	4	5	6	Extremely Comfortable-7
			16.7	25	33.3	25	
Question 8	Clearly Unacceptable-1	2	3	4	5	6	Clearly Acceptable-7
		4.3	13	13	30.4	30.4	8.7
Question 9	Much Cooler-1	2	3	4	5	6	Much Warmer-7
		4.2	12.5	45.8	29.2	4.2	4.2
Question 10 (Comprehension and concentration)	Extremely Negative-1	2	3	4	5	6	Extremely Positive-7
			29.2	20.8	29.2	16.7	4.2

to the acceptable limit. Comprehension and concentration scores remained largely neutral to positive, indicating no significant cognitive impact of the thermal environment.

Students' thermal sensation votes before and after the lesson showed a moderate-to-strong correlation (R^2=0.6462), indicating stable thermal perception throughout the lesson. The regression line (y=0.8657x + 0.4483) suggests a slight convergence toward neutral sensations, which may reflect partial thermal adaptation during occupancy. Overall, the results indicate that the time elapsed during the lecture did not significantly affect thermal comfort.

Figure 10 illustrates the variation of AMV with respect to seating location before and after the lesson. A positive trend was observed in both cases, indicating that students seated closer to the window reported higher thermal sensation votes than those seated farther away. The relationship was slightly stronger before the lesson ($R^2 \approx 0.32$) compared to after the lesson ($R^2 \approx 0.26$), suggesting a modest adaptive effect over time, as occupants gradually became accustomed to the thermal environment.

These findings confirm the presence of spatial thermal gradients within the classroom and highlight the sensitivity of occupant thermal perception to seating position, with façade-adjacent areas consistently associated with warmer sensations.

Results of Behavioral Observations

Camera recordings of occupancy provided additional context for interpreting the measurement and survey data. According to analysis of camera recordings (Figure 11), it can be concluded that students tended to avoid seating near the façades indicating behavioral adaptation in response to localized discomfort. Curtains were generally left partially open during morning and midday periods, which allowed solar penetration and contributed to elevated mean radiant temperatures, especially near south facade. The analysis further indicated that windows were generally operated intermittently, leading to additional solar gains and increased PMV values near the façades.

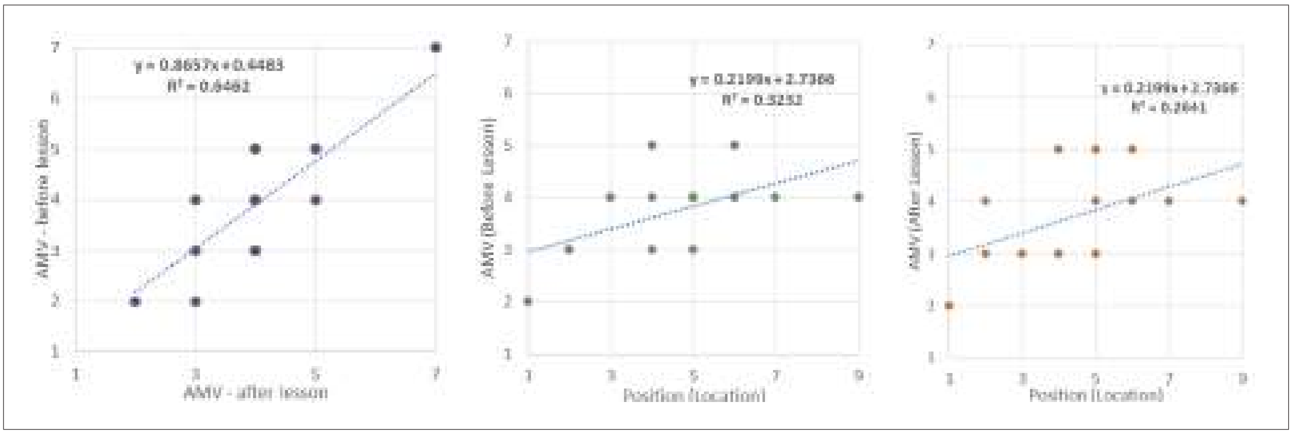


Figure 10. The variation of AMV before and after the lesson and relation with seating location.

Synthesis of Findings

Inter-room comparisons were conducted by statistically analyzing PMV data collected between 3–19 November, employing Mean Bias Error (MBE) and the coefficient of determination (R^2) as key performance indicators. The analysis revealed that the strongest agreement was observed between B-502 and B-501 (MBE ≈ –0.009; R^2 ≈ 0.65), reflecting the generally uniform thermal behavior of these two south-oriented classrooms despite B-501's southeast façade exposure. The relationship between B-503 (southwest-oriented) and B-502 (MBE ≈ –0.085; R^2 ≈ 0.55) exhibited moderate agreement, whereas the weakest correlation was found between B-503 and B-501 (MBE ≈ –0.094; R^2 ≈ 0.52), attributable to the combined effects of B-501's morning solar gains from the southeast and B-503's afternoon overheating due to southwest exposure.

These orientation effects resulted in distinct diurnal PMV: B-501 exhibited pronounced morning gradients, B-503 experienced elevated afternoon PMV peaks, while B-502, being purely south-facing, displayed a more balanced thermal profile across the day. Despite the differences in correlation strength, all MBE values remained well within the ±10% acceptability thresholds, indicating spatial/temporal effects. This outcome highlights the methodology's sensitivity to façade orientation effects and confirms its capacity to capture both temporal and spatial non-uniformities in thermal comfort performance. Consequently, the developed approach provides a reliable basis for informing evidence-based retrofit strategies and simulation-driven optimization (Figure 12).

Figure 13 illustrates the relationship between PMV and three key behavioral parameters: Curtain operation, window operation, and occupancy. Curtain operation exhibited a negligible correlation with PMV (R^2 ≈ 0.002), confirming that shading devices were largely kept in a fixed position regardless of thermal comfort conditions. On average, curtains remained closed 47.9% of the time, indicating that solar control was predominantly maintained in a closed state throughout the measurement period.

Window operation showed a weak but positive correlation with PMV (R^2 ≈ 0.06), suggesting a modest tendency to open windows under warmer conditions. However, the mean window opening rate was only 16.7%, demonstrating that natural ventilation was seldom adopted as an adaptive measure. Occupancy levels displayed only a very weak relationship with PMV (R^2 ≈ 0.01), indicating that fluctuations in student numbers contributed minimally to thermal variability.

Collectively, these findings reveal a behavioral pattern characterized by limited active adaptation, with solar control dominated by a consistently closed curtain state and window operation being infrequent.

Table 8 compares AMV and PMV values. B-503 exhibited the highest AMV (4.30) reflecting slightly warm sensations, but alongside a nearly neutral PMV (–0.04), consistent with its southwest exposure. B-502 presented the lowest PMV (–0.46), consistent with cooler indoor conditions, while B-501 remained near neutral but slightly cooler (AMV 3.5; PMV –0.27). The overall alignment between AMV and PMV indicates consistency between measured and perceived comfort, with differences explained by orientation-driven solar gains.

The integrated dataset, combining objective measurements, occupant surveys, and behavioral observations, provided a comprehensive assessment of thermal comfort that captured both physical and experiential dimensions. Localized overheating near south-facing façades was consistently detected, and occupants seated near the windows reported greater thermal dissatisfaction. These findings were corroborated by measurement and survey data, which indicated higher levels of thermal dissatisfaction and reduced lesson comprehension near the windows. Limited curtain and window use were insufficient to mitigate discomfort, resulting in persistent PMV levels above recommended comfort thresholds. The strong correlation between measured and perceived comfort indices validated the methodology and confirmed its capacity to accurately diagnose thermal comfort conditions.

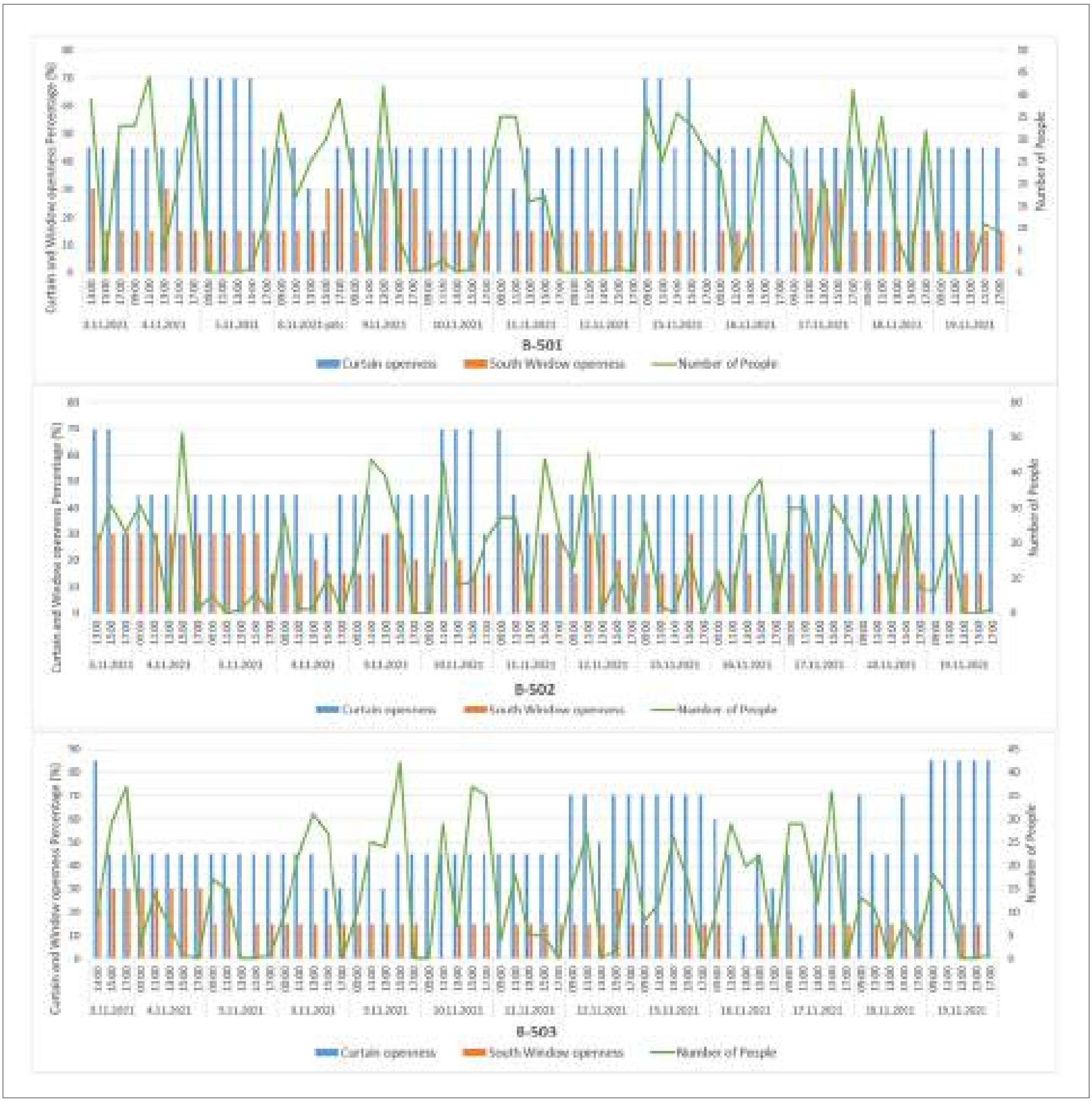


Figure 11. Occupancy (number of people), curtain (curtain openness percentage) and window (window openness percentage) operation of Classroom B-501, B-502 and B-503 from 8:00 AM to 5:00 PM between November 3–19, 2021 (except weekends).

DISCUSSION

The findings of this study highlight the interaction between measured thermal comfort conditions, occupant perception, and behavioral responses in university classrooms. PMV values near the south-facing façades exceeded comfort thresholds during afternoon hours, confirming the dominant effect of solar gains. The amphitheater configuration, with extensive south-facing glazing and tiered seating, intensified discomfort for students seated near the windows, while convective air movement contributed to localized heat accumulation. Despite these asymmetries, converted AMV scores were broadly consistent with PMV predictions, suggesting that the model provided a reasonable estimation of perceived comfort. Minor deviations near the façades are consistent with previous findings that predictive models may not fully capture adaptive tolerance in mixed-mode environments (de Dear & Brager, 1998; Humphreys & Nicol, 2002). The integration of subjective surveys allowed PMV results to

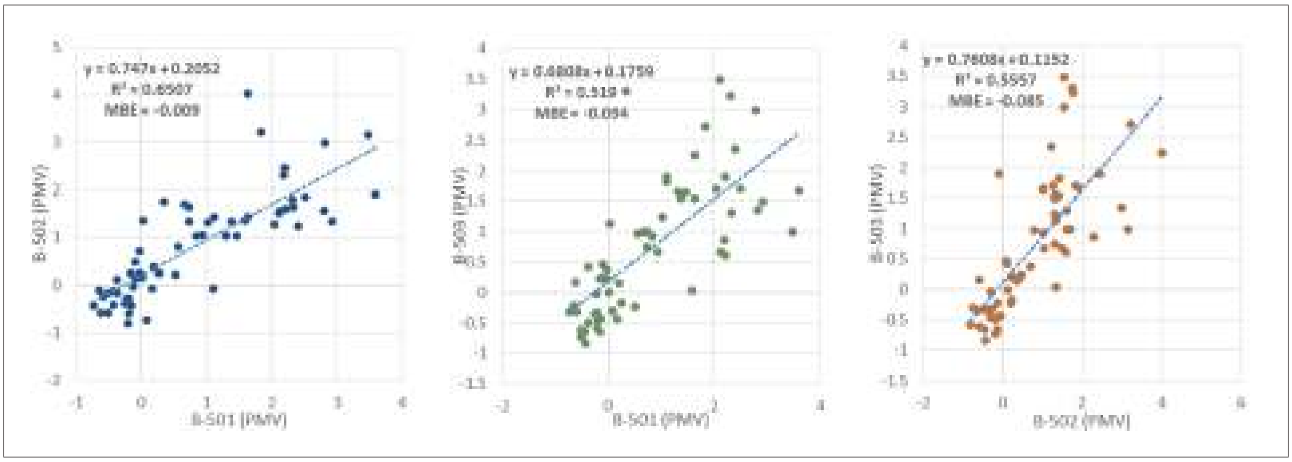


Figure 12. Comparison of classrooms (3–19 November).

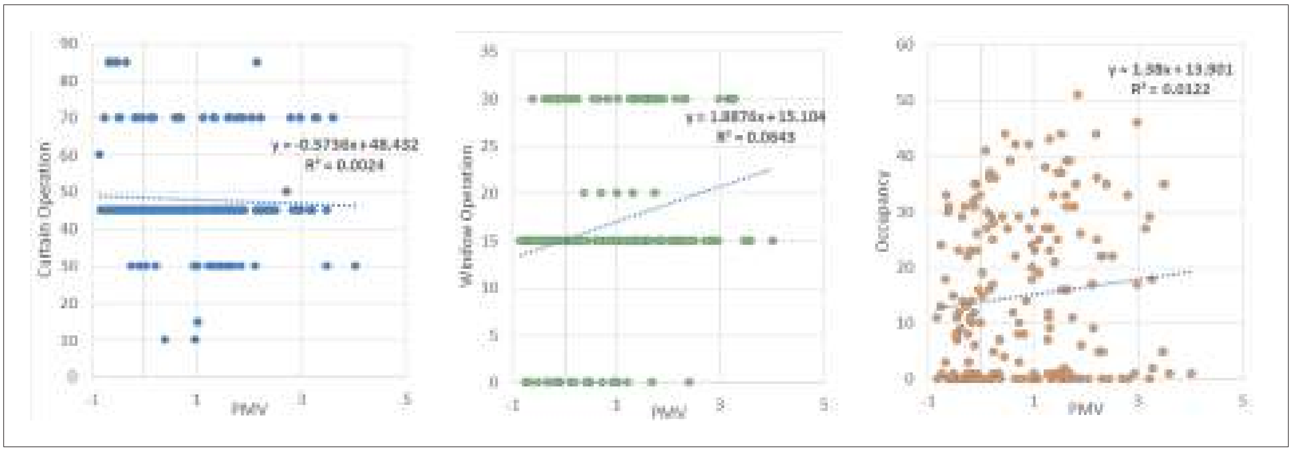


Figure 13. The comparison the relationship between PMV and curtain operation, window operation, and occupancy respectively.

be directly compared with occupant votes, thereby enhancing external validity. The results is consistent with the adaptive comfort framework proposed by Nicol and Humphreys (2002), which demonstrates that acceptable comfort ranges expand with outdoor climatic conditions, particularly in warm climates.

Table 8. Comparison of AMV and PMV.

	B-501	B-502	B-503
AMV			
Mean	3.50	3.70	4.30
Std.dev.	0.50	0.90	1.15
AMV (Converted)			
Mean	–0.5	–0.3	0.30
PMV			
Mean	–0.27	–0.46	–0.04
Std.dev.	0.26	0.34	0.29

It should be noted that although long-term measurements were conducted to evaluate thermal comfort across working place, surveys were applied on a single day at the same time with short-term measurements under overcast sky conditions, which limits the representativeness of the findings. As emphasized by Fabi et al. (2012), short-term or condition-specific studies may not capture seasonal variability, highlighting the need for longer-term studies. Therefore, it is recommended that future survey studies adopt seasonally distributed applications to better capture occupant variability.

Behavioral observations revealed limited adaptation: Curtains were kept closed nearly 48% of the time and windows were opened in ≈ 17% of cases, resulting in persistent overheating near façades. These results support Schweiker and Wagner (2016), who reported that occupants often underutilize available control opportunities, leaving them exposed to thermal discomfort. Furthermore, the observed avoidance of window-adjacent seats is consistent with Yan et al. (2015), who emphasized that spatial discomfort influences seating preferences and adaptive behavior.

Even under overcast conditions, façade transparency caused thermal effects, confirming the importance of solar control and occupant-centric solutions like automated shading and natural ventilation (Tzempelikos & Athienitis, 2007). According to findings, it is suggested that retrofit measures such as external shading, selective glazing, and adaptive interior systems are recommended to mitigate solar gains, particularly in southeast- and southwest-facing classrooms.

In summary, while predictive models such as PMV align reasonably well with occupant perception, their limitations in capturing adaptive tolerance and transient effects necessitate field-based validation. The integration of surveys and behavioral data strengthens validity, while the identified methodological constraints highlight the importance of extended monitoring and cross-seasonal applications.

CONCLUSION

This study developed and validated a field-based methodology for assessing thermal comfort in university classrooms with high window-to-wall ratios and strong solar exposure. By integrating objective measurements, occupant surveys, and behavioral observations, the approach provided a detailed assessment of thermal comfort conditions under real environmental conditions. Its application in three classrooms with different façade orientations confirmed its ability to capture spatial differences and the relationship between predicted and perceived comfort.

The results showed that southeast and southwest-facing classrooms experienced the highest thermal stress, while the south-facing classroom exhibited more uniform conditions. Behavioral observations revealed limited adaptation, with curtains largely closed and windows rarely used, indicating reliance on passive or automated systems.

While limited to three classrooms, the findings demonstrate the method's reproducibility. This study demonstrates the value of a field-based, standards-compliant methodology for assessing thermal comfort under real-word conditions. The close correspondence between AMV and PMV supports the validity of the approach, and most PMV values were within acceptable comfort ranges.

Future research should extend this methodology to different building types, climates, and cultural contexts; incorporate longer-term monitoring studies across multiple seasons; and integrate additional indoor environmental parameters such as daylight quality, acoustics, and indoor air quality. Expanding survey questions to capture transient perceptions, thermal perceptions, and cognitive performance would also deepen understanding of comfort dynamics. Overall, this study demonstrates the potential of a standards-compliant, field-based methodology to bridge the gap between predicted indices and lived experience.

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REFERENCES

ASHRAE. (2023). *Thermal environmental conditions for human occupancy. American Society of Heating, Refrigerating and Air-Conditioning Engin*eers. ANSI/ASHRAE Standard 55-2023.

Bay Şahin, E., & Elnimeiri, M. M. (2025). Thermal comfort in social housing: A case study from Türkiye's hot-dry region. *Megaron, 20*(2), 147–165. https://doi.org/10.14744/megaron.2025.55890

Brager, G. S., & de Dear, R. J. (2001). Climate, comfort & natural ventilation: A new adaptive comfort standard for ASHRAE Standard 55. *ASHRAE Transactions, 107*(2), 1–16.

Dawe, M., Karmann, C., Schiavon, S., & Bauman, F. (2021). Field evaluation of thermal and acoustical comfort in eight office buildings. *PLOS ONE, 16*(9), e0258888. https://doi.org/10.1371/journal.pone.0258888

de Dear, R. J., & Brager, G. S. (1998). Developing an adaptive model of thermal comfort and preference. *ASHRAE Transactions, 104*(1), 145–167. https://escholarship.org/uc/item/4qq2p9c6

Fabi, V., Andersen, R. V., Corgnati, S. P., & Olesen, B. W. (2012). Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and building energy consumption. *Building and Environment, 58*, 188–198. https://doi.org/10.1016/j.buildenv.2012.07.009

Fanger, P. O. (1970). *Thermal comfort: Analysis and applications in environmental engineering*. Danish Technical Press

Hong, T., Malik, J., Krelling, A., O'Brien, W., Sun, K., Lamberts, R., & Wei, M. (2023). Ten questions concerning thermal resilience of buildings and occupants for climate adaptation. *Building and Environment,* *244*, 110806. https://doi.org/10.1016/j.buildenv.2023.110806

Humphreys, M. A., & Nicol, J. F. (2002). The validity of ISO-PMV for predicting comfort votes in everyday thermal environments. *Energy and Buildings, 34*(6), 667–684. https://doi.org/10.1016/S0378-7788(02)00018-X

ISO. (2019). *Ergonomoics of the phsycal enironment*. ISO 10551:2019.

ISO. (2025). *Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. International Organization for Standardization. ISO 7730:2025

Jing, W., Qin, Z., Mu, T., Ge, Z., & Dong, Y. (2024). Evaluating thermal comfort indices for outdoor spaces on a university campus. *Scientific Reports, 14*, 21253. https://doi.org/10.1038/s41598-024-71805-5

Kim, J., Schiavon, S., & Brager, G. (2018). Personal comfort models—A new paradigm in thermal comfort for occupant-centric environmental control. *Building and Environment, 132*, 114–124. https://doi.org/10.1016/j.buildenv.2018.01.023

Mıhlayanlar, E., Öztuna, S., & Büyükakın, B. (2017). Investigation of thermal comfort conditions in higher education facilities: A case study for engineering faculty in Edirne. *Journal of Thermal Science and Technology, 6*(1), 71–79

Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings, 34*(6), 563–572. https://doi.org/10.1016/S0378-7788(02)00006-3

Schweiker, M., & Wagner, A. (2016). The effect of occupancy on perceived control, neutral temperature, and behavioral patterns. *Energy and Buildings, 117*, 246–259. https://doi.org/10.1016/j.enbuild.2015.10.051

Sun, R., Duarte Roa, C., Raftery, P., & Fierro, G. (2022). *Enabling portable and reproducible long-term thermal comfort evaluation with Brick schema and Mortar testbed*. ASHRAE.

Şuta, O., & Zencirkıran, A. (2024). Investigation of the determinants of user satisfaction in social mass housings in Edirne during the COVID-19 period. *Megaron, 19*(2), 184–203. https://doi.org/10.14744/megaron.2024.74050

Tzempelikos, A., & Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. *Solar Energy, 81*(3), 369–382. https://doi.org/10.1016/j.solener.2006.06.015

Yan, D., O'Brien, W., Hong, T., Feng, X., Gunay, H. B., Tahmasebi, F., & Mahdavi, A. (2015). Occupant behavior modeling for building performance simulation: Current state and future challenges. *Energy and Buildings, 107*, 264–278. https://doi.org/10.1016/j.enbuild.2015.08.032

Yao, R., Li, B., & Liu, J. (2009). A theoretical adaptive model of thermal comfort – Adaptive Predicted Mean Vote (aPMV). *Building and Environment, 44*(10), 2089–2096

Zhang, Y., Zhou, X., Zheng, Z., Oladokun, M. O., & Fang, Z. (2020). Experimental investigation into the effects of different metabolic rates of body movement on thermal comfort. *Building and Environment, 168*, 106489. https://doi.org/10.1016/j.buildenv.2019.106489

Zoroğlu, F., & Zorer Gedik, G. (2022). A field study on thermal comfort in the shopping malls in a temperate humid climate. *A/Z : ITU Journal of Faculty of Architecture, 19*(1), 103–118. https://doi.org/10.5505/itujfa.2022.62582

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Article

Exploring the impact areas of cohousing: A scoping review and thematic analysis of post-2000 studies

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ABSTRACT

This article examines the "cohousing" model as an alternative response to the commodification of housing and the accompanying environmental, social, and economic challenges. Focusing on cohousing as a holistic framework for social development, it traces the historical evolution of collaborative housing models to highlight their conceptual distinctions. A scoping review was conducted to conceptually clarify the impacts of cohousing, as it calls for a transformation of the home and all related factors as a form of daily life reform. For this purpose, studies on the cohousing model published between 2000 and 2024 were examined using the Web of Science and Scopus databases. From these, 87 articles that met the criteria were selected, and the approaches they used to address this housing model were analyzed. By identifying one or more contexts in which cohousing was studied in each article, a map of academic and practical impact areas was created. The analysis revealed that cohousing is addressed within five main themes: Political economy, social capital, resident profiles, design, and gender. These themes and their sub-themes are presented in a table reflecting the research trends of the given period (Table 2). The findings and evaluations aim to offer a comprehensive, interdisciplinary perspective for policymakers, local governments, and intentional communities interested in cohousing.

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INTRODUCTION

This article examines the cohousing model, which has emerged as an alternative response to the commodification of housing and the accompanying environmental, social, and economic challenges. Cohousing, understood here as a collaborative and shared housing approach, offers a means of rediscovering sociality through spatial practices. Rather than representing a noval invention, it is a model shaped by accumulated social and spatial experiences throughout history. The following part situates the contemporary cohousing model within its historical and intellectual context, tracing the ideas and experiences that have influenced its evolution. Due to its varying applications in different countries, the term cohousing is used in this study as an umbrella term derived from the Danish word *bofaellesskaber*, meaning "living communities." In this regard, the Danish model, which encompasses a intergenerational community of people of all ages, genders, ethnicities, and financial means, continues to be the gold standard for cohousing worldwide.

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The purpose of this research is to conceptually clarify the sphere of influence of cohousing by mapping and analyzing the existing literature. Starting with the research question, "What is known about the sphere of influence of cohousing?" a scoping review method was employed to avoid overlooking the different layers of the social and political infrastructure that transform space. The analysis of 87 full-text articles provides a comprehensive and interdisciplinary overview relevant to policymakers, local authorities, and intentional communities. Ultimately, the study demonstrates that contemporary cohousing is not an isolated phenomenon but a continuation of historical and philosophical movements. By examining how themes such as political economy, social capital, and gender intersect with the historical roots of cohousing, it bridges the gap between theoretical foundations and contemporary practice. The article proceeds by outlining the inclusion and exclusion criteria applied in the review, followed by the presentation of the main findings.

HISTORICAL BACKGROUND

Cohousing's historical development may not have followed the same trajectory as housing throughout architectural history. The background of cohousing can be collectively represented by the three anthologies discussed in this study. These anthologies are respectively, a) the communities living together as communes that embraced Thomas More's *Utopia* and were called utopian socialists due to their concern for equality, b) material feminists who questioned the role of women in the home and society, and c) feminist architects who challenged architecture embedded with gendered values. Figure 1 illustrates this growth process through the metaphor of a snowball, showing the interrelated nature of these anthologies. The failure of one anthology to reach completion suggests that subsequent processes may also remain incomplete or never be fully realized. For this reason, the chronological sequence and the broadening of the concept are explained in terms of an internal evolution.

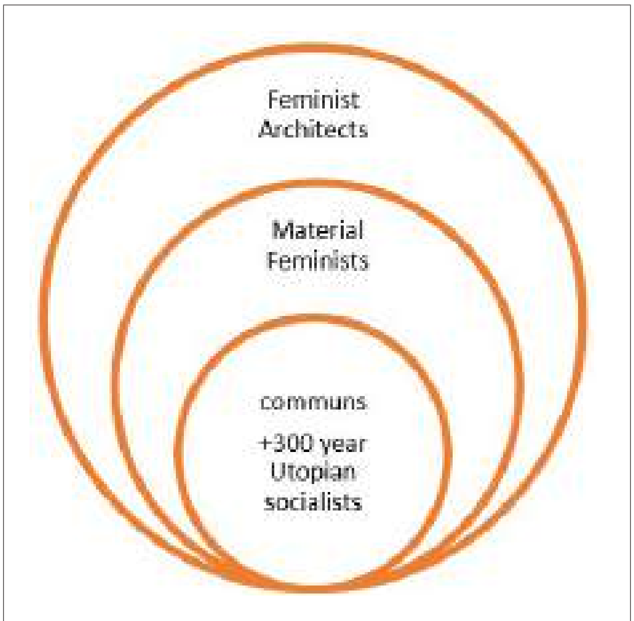

Figure 1. Cohousing background diagram (Designed by the Authors).

Utopian Socialists

The concept of communal habitation was born when the vegetarian commune Homakoeion was founded 2000 years ago (Meltzer, 2006). The term "Utopia" was first used by Thomas More in his book of the same name in 1516 (Hayden, 1977; Vestbro and Horelli, 2012). In this utopia, which translates to "a good and nowhere place," men and women have equal rights, and private property does not exist (Vestbro & Horelli, 2012). More's notion of utopia is said (Vestbro & Horelli, 2012) to have influenced the religious and ideologically driven groups later referred to as "utopian socialists" (Hardy, 1979; Hayden, 1977). In response to the inequalities brought about by the Industrial Revolution, these communities experimented with various communal housing programs in the 1800s (Hardy, 1979). These ideological and religious groups expressed their shared values through architecture that reflected their common beliefs.

Material Feminists

The American Woman's Home, an instruction manual, was published in 1869 by Catherine Beecher and her sister, Harriet Beecher Stowe. The Beecher sisters envisioned women as secluded yet responsible for every aspect of household life in an effort to maximize their authority (Hayden, 1981). The term "material feminists" was used to describe this subset of feminists who focused solely on material concerns. Although Beecher and other material feminists sought to enhance women's power, they failed to address class inequality by concentrating exclusively on gender. Nonetheless, their ideas laid the foundation for later emancipatory efforts.

Feminist Architects

Feminist architects started by challenging the isolated domestic architecture, learning from the mistakes of earlier, unidirectional material methods. In 1880, Marie Stevens Howland introduced the concept of "unified labor" by designing a city layout in Topolobampo, Mexico, featuring apartment hotels with sufficient childcare and kitchenless homes (Hayden, 1978). Between 1880 and 1890, the construction of collective kitchens, laundromats, and separate hotels began. The first public kitchen initiative was launched in 1890 by Ellen Swallow Richards and Mary Hinman Abel (Hayden, 1978). Based on their trial, the two women laid the foundation for cooperative housing and promoted the idea of "cooperative housekeeping." In the following years, cooperative cleaning, dining clubs, and cooked-food delivery gained popularity.

In California, Alice Constance Austin developed a housing design in 1915 that included kitchenless homes connected to a common kitchen (Hayden, 1978). A critical lesson emerged from these two unsuccessful city-scale projects: Smaller-scale initiatives were more viable. The Swedish model, widely regarded as the earliest instance of cohousing, was the first practical application of these progressive concepts on a smaller scale.

These concepts also took shape with similar developments in Europe. For instance, the "Fick's Collective" building, constructed in Copenhagen in 1903, was the first structure in Europe to feature a central kitchen, following similar advances in America (Vestbro, 1992). Hemgården Centralkök, built in Stockholm between 1905 and 1907, was the second single-kitchen home in Europe (Vestbro, 1992). The Hemgården building, accessible from the central kitchen via service elevators, was constructed to reduce expenses by hiring fewer maids and to make the apartments smaller, rather than to promote women's employment outside the house. In 1935, architect Sven Markelius and social reformer Alva Myrdal introduced the term *kollektivhus* (collective housing) in Sweden (Caldenby, 2021). Unlike earlier cases that aimed to replace domestic servants, they viewed community living as a means to enable women to combine paid labor outside the home with domestic chores. Services in the first *kollektivhus* were provided by paid staff, and the building featured both a dining hall and a nursery. The concept of collective housing in Sweden declined in the 1950s due to the rise of the housewife ideal and the absence of labor shortages. However, between 1965 and 1974, the Swedish government launched the "Million Program," offering state support for the construction of one million homes (Caldenby, 2021). Interest in collective housing grew during this period, as these new residences lacked social features, gender equality, and ecological ideals (Caldenby, 2021). The *Small Collective House*, the first Swedish model for shared housework, was created in 1977 at the behest of a group of feminists. It was based on cooperation rather than division of labor and operated without employed staff (Caldenby, 2021; Saarikangas and Horelli, 2018; Blomberg and Kärnekull, 2019).

The Swedish model served as inspiration for Denmark's shift to *Bofællesskab* following the initial effort at centralized kitchens (Larsen, 2019). In 1960, Copenhagen saw the construction of the first *Bofællesskab*. Around the same time, the Netherlands adopted the Danish model, which would later be regarded as the forerunner of modern cohousing. Two American architects, McCamant and Durrett, were drawn to Denmark's innovative cohousing concept, primarily driven by social interaction. As a result, they published *Cohousing: A Contemporary Approach to Housing Ourselves* in 1988, the first book to introduce the term "cohousing." Following its publication, cohousing began to gain traction in the US as a growing trend. Since 1990, the US cohousing model has been implemented as a modified version of the Danish model, adapted to its own sociocultural framework (Fromm, 2000a).

Instead of being a top-down paradigm, these four anthologies show how a housing model evolves through experimentation and necessity. In terms of implementation, governance, or architectural typology, the concept of cohousing has produced several variations over time. Alongside the term "cohousing," various countries have also created other terms with more or less specific definitions.

The Netherlands and the Flemish region of Belgium (prior to 2011[1]) (De Vos & Spoormans, 2022) referred to cohousing as "Central Wonnen," meaning central living. In contrast, the Czech Republic and the rest of Belgium use the term "cohousing" (Vestbro, 2010). In Germany and Austria, the term "Bougruppen" is used, which refers to co-living, although the governance structure differs from that of cohousing. In France the term "Habitat Participatif" is used, while the UK, Belgium, and more recently, France, refer to the concept as "Community Land Trust" (CLT). Spain and Switzerland, on the other hand, use the term "cooperative." However, some of the phrases, shaped by national housing regulations, are more inclusive than others. For instance, in the UK, "community-led housing" is a broad term that encompasses "cohousing," "cooperative housing," and "CLTs" (Griffith Jepma & Savini, 2024). Some authors also use inclusive terminology. According to Arbell (2023), community-led housing includes CLTs, cooperative housing, cohousing, self- and custom-built housing, and self-help housing. Similarly, Czischke (2018) categorizes self-organized housing, community-led housing, and participative housing under the broader term "collaborative housing." To conduct research specifically on the cohousing model, it is essential to distinguish between these various housing models based on their unique characteristics. Therefore, the next section provides a detailed explanation of the decision-making process in light of these distinctions.

The philosophical and practical foundations of contemporary cohousing are the result of an accumulation of ideas from utopian socialism, material feminism, and feminist architecture. These three approaches, each contributing to a re-evaluation of community and household space, collectively built the groundwork for modern cohousing. This historical progression culminated in the Danish *Bofællesskab* model, which is seen as the direct ancestor of today's cohousing movement. Therefore, cohousing is a way of life that brings together social and spatial values, shaped by a rich history of shared ideals.

METHOD

The review was conducted as a qualitative mapping study following Arksey and O'Malley's methodological framework, which was the first to be published in this field (Levac et al., 2010) and remains in use today[2]. This framework conceptualizes *scoping* as a process of "mapping" evidence to define the breadth and depth of a subject, although its definition and purpose remain debated (Arksey & O'Malley, 2005; Levac et al., 2010; Tricco et al., 2018). This approach provides a sufficiently detailed procedure to enable replication of the study by other researchers. The review consists of five steps.

The first step in identifying the characteristics that influence cohousing—a housing style more prevalent in some countries and absent in others—was to formulate the following research question: *What is known about the sphere of influence of cohousing?* The second step involved searching for relevant research, beginning with a review of the historical evolution, terminology, and diversity of the literature, without restrictions on publication year, type, or language. As a result of this investigation, the first and second sections of the study were structured accordingly. This study examines the term "cohousing" and the model it represents, as previously defined by McCamant and Durrett (2011) and described by Vestbro (2010) as "the most appropriate term for housing to refer to a sense of togetherness and community." In this context, the second step also included a search for studies that adhered to the cohousing principles (Table 1).

For this study, the Web of Science (WoS) and Scopus databases were selected. The earliest instances of cohousing after 1970 in Sweden, Denmark, and the Netherlands constitute the first wave, which is categorized into waves based on time and geographic context. The second wave refers to the North American model that emerged in the 1990s, while the third wave includes models from Southern Europe, South America, Australia, and East Asia that appeared after 2000. Therefore, the study's scope is defined as post-2000 (2000–2024, up to and including April), when cohousing began to gain traction in various countries worldwide.

To select research for the third step, the papers were studied in three phases: Full text, abstract, and title. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Tricco et al., 2018) was applied in the fourth step to refine the articles, which involved graphing the data (Figure 2). The 87 articles selected for full-text reading were compiled into an Excel spreadsheet for the fifth step, which focused on aggregating and summarizing the findings. The approaches used as the basis for the cohousing review were noted in columns, and related themes were grouped under a common cluster name (Table 2). As a result, all articles were categorized into five thematic clusters.

FINDING

This section presents the results of the full-text analysis of 87 articles. The findings, derived directly from the literature, are categorized into five thematic clusters, offering a

Table 1. Criteria for inclusion and exclusion of paper during the review.

	Inclusion criteria	Exclusion criteria
Management/Development Type	- Bottom-up management, including the project design and processes. - Bottom-up management, excluding construction.	- Residents not involved in project or management. - Top-down approaches (state or private company).
Stakeholders	- Intentional community*. - Self-built housing. - Cooperative/NGO-built housing. - Architect-designed housing initiated upon community request.	- State- or privately-led housing.
Architectural requirements	- Common indoor/outdoor areas.	- No shared area management.
Ideological	- Social, ecological, economic and gender ideologies aligned with intergenerational housing.	- Affordable housing only. - Senior cohousing. - Eco-villages.
Article type	- Articles in WoS and Scopus.	- Book sections. - Book reviews. - Conference reports.
Interdisciplinarity	- Articles from disciplines related to cohousing.	- Covid-19-related reviews.
Publication date	- Published 2000–2024 (inclusive).	- Published before 2000
Publication language	- English and Turkish.	- Languages other than English and Turkish.

*'Intentional community' refers to a multi-family community that is intentionally gathered together with the intention of housing together.

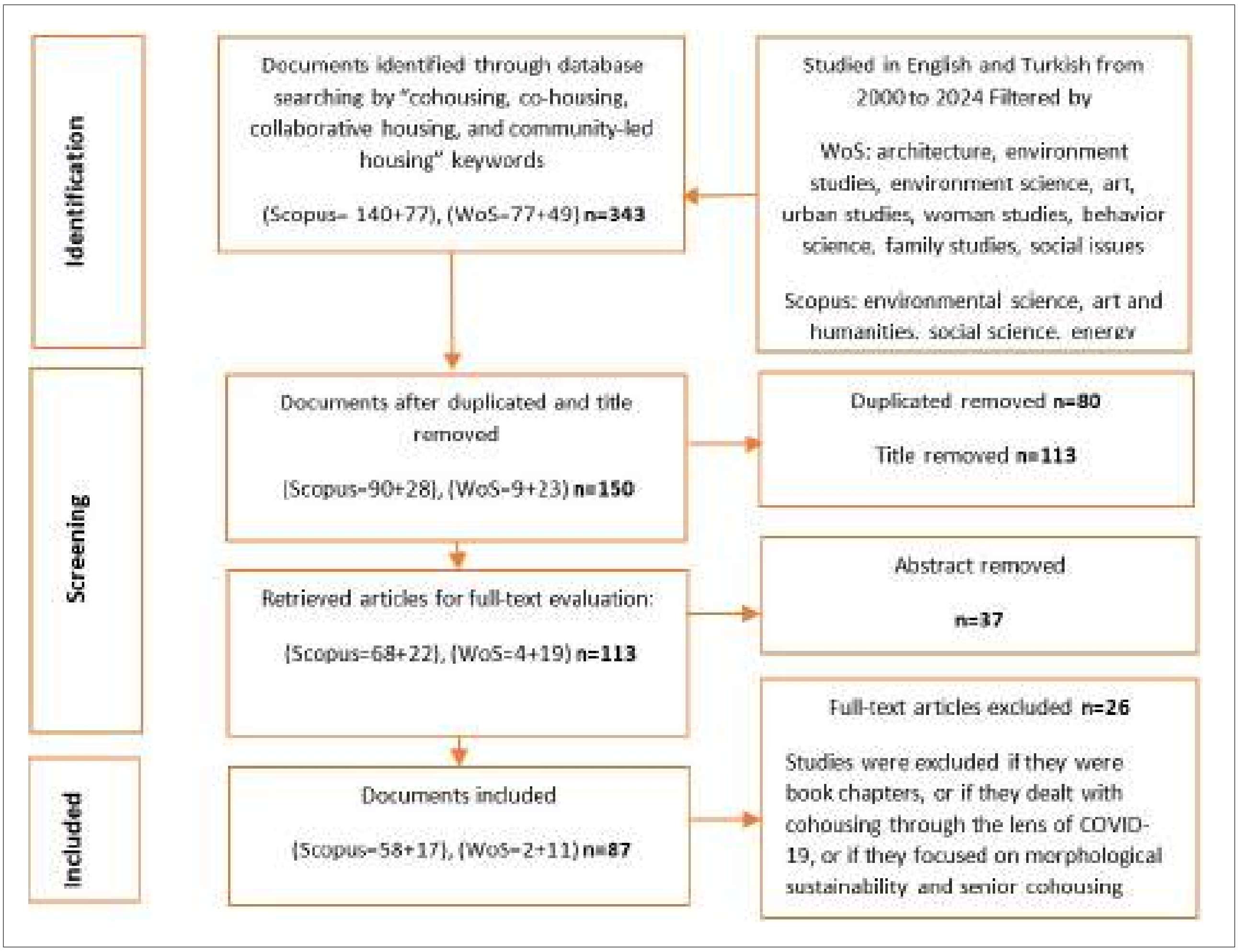

Figure 2. PRISMA flow diagram for elimination and inclusion of articles.

comprehensive overview of the field's current state. Table 2 provides a visual representation of these themes and their sub-clusters. A detailed discussion and interpretation of these results will be provided in the Discussion section.

Political-Economics

This thematic cluster included the majority of the analyzed articles, with 50 out of 87 falling under this category. The main political-economic cluster has four sub-clusters: Housing policies, barriers to expansion, tenure, and economic evaluation. In addition to studies exploring the desire to further develop cohousing (Arbell, 2022; Blomberg and Kärnekull, 2019; Boyer and Leland, 2018; Kvietkute and Hauge, 2022), this cluster includes research describing successful policy decisions and support in countries that have already achieved positive outcomes (De Vos and Spoormans, 2022; Put and Pasteels, 2022; Lenel, Demonty, & Schaut, 2020; Scheller and Thörn, 2018; Droste, 2015; Garcia, 2023). The studies in the first group report the effects of political variations across countries and often include comparative analyses. They examine legal frameworks in different national contexts. The second set of research focuses on identifying the policies that lead to successful outcomes within specific geographic settings. Beyond global geopolitical distinctions, variations in municipal support within countries—such as differences between Austrian states (Lang and Stoeger, 2018) and Swedish municipalities (Blomberg and Kärnekull, 2019)—have demonstrated that national policies produce varied results. For instance, the German government encourages cohousing initiatives during the planning, construction, or land distribution phases, and the existing literature frequently highlights municipal policies that encourage these projects (Lang and Stoeger, 2018; Droste, 2015; Laine, Helamaa, Kuoppa, & Alatalo, 2018; Schelisch, Spellerberg, & Vollmer, 2019).

According to studies examining the relationships between residents, developers, and other actors involved in the cohousing development process, the primary barrier to advancing this practice is the lack of awareness and knowledge among stakeholders (Arbell, 2022; Put and Pasteels, 2022; Horňáková and Jíchová, 2020; Blomberg and Kärnekull, 2019; Arrigoitia and Tummers, 2019; Thankamoniyan and

Table 2. Thematic clustering of studies with full text reading.

	POLITICAL-ECONOMICS Theme 1				SOCIAL CAPITAL Theme 2			RESIDENT ANALYSIS Theme 3			DESIGN Theme 4	GENDER Theme 5		
ARTICLES	TENURE	ECONOMIC DOWNSIZING, AFFORDABILITY	EXPANSION BARRIERS	HOUSING POLICIES, STAKEHOLDERS	HEALTH	SENSE OF COMMUNITY	SOCIAL SUPPORT	MOTIVATIONS	DEMOGRAPHIC ANALYSIS	BEHAVIORAL TRANSFORMATION	DESIGN	COMMONS	FEMINISM	CARE
1						■	■							
2							■				■			
3						■					■			
4	■			■							■			
5							■							
6							■							
7												■	■	■
8			■	■										
9				■							■			
10						■	■							
11											■			
12		■										■		
13					■									
14	■			■										
15								■						
16				■										
17	■					■					■			
18				■										
19		■					■		■					
20		■									■			
21							■							
22			■						■					
23		■						■						
24						■	■							
25				■				■	■					
26					■					■				
27	■	■												
28			■	■										
29			■	■							■			
30						■					■			
31			■						■					
32		■		■										
33					■		■							
34		■		■							■			

Table 2. Continue.

ARTICLES	POLITICAL-ECONOMICS Theme 1				SOCIAL CAPITAL Theme 2			RESIDENT ANALYSIS Theme 3			DESIGN Theme 4	GENDER Theme 5		
	TENURE	ECONOMIC DOWNSIZING, AFFORDABILITY	EXPANSION BARRIERS	HOUSING POLICIES, STAKEHOLDERS	HEALTH	SENSE OF COMMUNITY	SOCIAL SUPPORT	MOTIVATIONS	DEMOGRAPHIC ANALYSIS	BEHAVIORAL TRANSFORMATION	DESIGN	COMMONS	FEMINISM	CARE
35											■			
36		■		■							■			
37							■			■				
38							■	■						
39			■											
40					■		■		■					
41				■							■			
42			■											
43	■		■	■										
44			■	■										
45			■	■										
46		■		■			■							
47			■	■										
48			■	■										
49			■				■		■					
50		■		■										
51				■										
52			■	■										
53				■										
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59							■				■			
60				■										
61		■											■	
62							■	■						
63				■									■	■
64				■										
65	■								■					
66				■										
67				■			■							
68				■										

Table 2. Continue.

ARTICLES	POLITICAL-ECONOMICS Theme 1				SOCIAL CAPITAL Theme 2			RESIDENT ANALYSIS Theme 3			DESIGN Theme 4	GENDER Theme 5		
	TENURE	ECONOMIC DOWNSIZING, AFFORDABILITY	EXPANSION BARRIERS	HOUSING POLICIES, STAKEHOLDERS	HEALTH	SENSE OF COMMUNITY	SOCIAL SUPPORT	MOTIVATIONS	DEMOGRAPHIC ANALYSIS	BEHAVIORAL TRANSFORMATION	DESIGN	COMMONS	FEMINISM	CARE
69						■	■							
70						■				■				
71					■	■	■							
72						■	■							
73		■								■				
74							■							
75														■
76									■		■			
77			■										■	■
78													■	■
79		■			■									
80			■						■					
81						■	■				■			
82			■				■							
83										■				
84						■					■			
85								■						
86			■					■			■			
87						■								

* The articles included in the full text review listed from 1 to 87 are listed chronologically and presented in Appendix.
* The reason why the total number of articles belonging to clusters is not 87 is that some articles have worked on more than one theme.

Jagadisan, 2021; Williams, 2005a; Czischke, 2018). The level of interest in cohousing has also been analyzed in relation to its development criteria (Boyer and Leland, 2018). Boyer and Leland (2018) examine this in detail and discover that those who express interest in cohousing are not necessarily the same as those who become residents. Based on this, they speculate that the slow growth of cohousing is not due to a lack of interest but rather to its limited accessibility. This finding indicates that multiple factors influence whether individuals adopt a particular cohousing model, and the relationship between expressed interest and adoption remains inconclusive (Boyer and Leland, 2018). In their attempt to quantify these factors through a sample, Sanguinetti and Hibbert (2018) found that individuals who were attracted to cohousing and genuinely wished to live in such communities have distinct demographic characteristics compared to those who have previously lived in cohousing. They identified that the level of experience with cohousing was the most significant difference (Sanguinetti and Hibbert 2018). The literature suggests that limited awareness, interest, and expertise contribute to the niche status of cohousing in many countries.

In addition to criticizing housing policies that encourage individual ownership, studies examining another subcategory, tenure, have explored concerns surrounding the ownership of private cohousing units (Larsen, 2019; Blandy, 2023; Bossuyt, 2021; Beck, 2020). Germany has made significant progress in cohousing, primarily due to its strong rental housing tradition and recent municipal subsidies

(Schelisch et al., 2019). According to Bossuyt (2021), the interests of residents, including communal behaviors, are directly linked to the ownership, management, and concession rights in a shared housing model. In summary, the political, economic, and legal dimensions of tenure are essential to the accessibility of cohousing.

Support for self-build initiatives has grown in several European nations in response to the economic crisis. This shift is interpreted in the literature as emphasizing collective approaches in response to economic challenges in housing. However, it is important to realize that providing affordable housing is not the only economic solution to the housing crisis. While cost is a significant consequence of cohousing, it is not its primary objective. Product-related factors, such as the use of low-cost and potentially subpar materials, can impact overall construction costs and may lead to long-term environmental issues. In contrast, process-related factors, such as organizational structure, level of involvement, and construction time, also influence costs during the building phase (Brysch and Czischke, 2022). Furthermore, achieving high energy efficiency and privacy standards often comes at a higher cost (Brysch and Czischke, 2022). The literature indicates that cohousing affordability is influenced by multiple factors, suggesting it should not be considered a singular concept. For instance, in the Netherlands, self-built housing is generally more affordable than turnkey housing (Bossuyt, Salet, & Majoor 2017). However, successful examples in the UK have been observed to compromise on affordability (Arbell, 2022).

The economic impact of cohousing extends beyond personal assets. Housing patterns and consumption habits are directly influenced by the UN's adoption of "economic growth" as the eighth Sustainable Development Goal in September 2015. According to research, sharing and cohabitation are significant approaches to achieving social, ecological, and economic sustainability (Scheller and Thörn, 2018; Savini, 2023; Lietaert, 2010). However, these studies also draw attention to the tensions between economic growth and sustainability. Cohousing addresses issues such as waste management and the reduction of resource use, including energy, land, and material goods (Williams, 2008).

Social Capital

The subthemes of social support, health, and sense of community are all part of the social capital thematic cluster (33 articles out of 87). Realizing social interaction within physical space has been frequently reported in the literature as contributing to social sustainability. The reviewed literature indicates that declines in social harmony and transformations in traditional values are factors associated with the emergence of cohousing (Nayak, Dash, Amin, & Priyashantha, 2023; Jarvis and Bonnett, 2013). Most studies assume that cohousing provides benefits such as social support (fulfilling needs), social integration (counteracting isolation), belonging, security, and community (Nayak et al., 2023; Markle R, et al., 2015; Sanguinetti, 2014; Cortés-Urra et al., 2023; Ruiu, 2016; Moradi and Hoseini, 2022). These findings are further supported by qualitative research highlighting the positive effects of cohabitation on well-being, active living, and healthy eating (Schetsche, Jaume, Gago-Galvagno, & Elgier, 2021; McClatchey et al., 2023; Arbell, 2022; Kehl and Then, 2013; Warner, Sutton, & Andrews, 2020).

According to Putnam (2000), social capital consists of elements of social organization, including connections, conventions, and trust that promote coordinated behavior and enhance societal efficiency. Putnam's (2000) definition of social capital is frequently used in contemporary literature. The cultural and social capital of a society often includes education levels, knowledge and skills, tools used, and books read (Arbell, 2022). In the context of cohousing, Ruiu (2016) suggests that self-management, decision-making involvement, and physical design contribute to the formation of social capital. Williams (2005a) asserts that building social capital can lead to economic benefits such as increased GDP, a more productive workforce, improved education, and reduced crime rates. Cohousing has been associated with social inclusion and the development of social capital in the literature. Civic engagement is another concept examined in this context. Research shows that cohousing residents demonstrate high levels of civic involvement, a key component of social capital, as evidenced by studies conducted in the United States (Berggren, 2020), Germany (Kehl and Then, 2013), and Italy (Bianchi and Costa, 2024).

Resident Analysis

The sub-clusters of motivation, demographic analysis, and behavioral transformation comprise the resident analysis cluster, which includes 23 of the examined publications. Most of these studies are based on case studies and/or data collected through resident surveys and interviews. These studies collectively produce a sociodemographic map of cohousing by depicting the characteristics of individuals who currently reside in or intend to move into cohousing communities. Numerous studies reveal that cohousing residents are predominantly middle-aged, white, educated, and middle-class individuals (Arbell, 2022; Jakobsen and Larsen, 2018; Sanguinetti and Hibbert, 2018; Berg, Wielen, Maussen, & Arentze, 2020; Lang, Carriou, & Czischke, 2018; Korpela, 2012). However, Arbell (2022) suggests that cohousing, as a conscious communal effort, may face challenges regarding inclusivity due to its high cultural capital.

Studies under the motivation sub-cluster, which examine the reasons individuals choose cohousing, have identified a variety of social (e.g., sociality, security, and gender), ecological, and economic motivations, influenced by the geopolitical context of each country (Wang, Pan, Hadjri, 2020; Markle et al., 2015; Kvietkute and Hauge, 2022; Vestbro, 2000; Fromm, 2000a; Chatterton, 2013). Privacy concerns, however, remain the primary factor discouraging individuals from joining cohousing communities (Vestbro, 2010; Put and Pasteels, 2022; Thankamoniyan and Jagadisan, 2021; Williams, 2008; Holtzman, 2024). The behavioral transformation sub-cluster focuses on the behavioral changes that cohousing participants experience and the behavioral differences they exhibit. These studies report increased social cohesion (Schetsche et al., 2021; Berggren, 2020; Boonstra, 2016; Sanguinetti, 2014) and heightened ecological sensitivity (Meltzer, 2000).

Design

The design cluster, which has 21 articles, is the only topic cluster in the literature review that is not further subdivided into smaller clusters. However, rather than existing independently, this cluster is constantly linked to the social capital, gender, and political economy clusters. Cohousing has been described in the literature as distinct from other co-living efforts due to its focus on social architecture (Ruiu, 2017). With a focus on participation-specifically involvement in decision-making-social architecture frames the building as both a product and a process. According to Ruiu (2017), participation is the primary characteristic that differentiates cohousing from conventional apartment complexes. In a fully constructed environment, residents have no physical control over the space and no social influence over other residents (Andersen and Lyhne, 2022). Participation, however, can reduce building costs, as noted by Brysch and Czischke (2022) and De Jorge-Huertas (2020), who focus on cost-related aspects of both the design and management process. Social architecture processes in cohousing enable residents, according to the literature, to participate in the consideration and implementation of their needs. Jarvis (2015) asserts that social architecture operates through interactions between people and place, reflection, learning, practice, and performance, as well as unseen emotional components such as motivation and well-being. The learning process through practice also results in behavioral changes.

One of the key components of cohousing is the use of a bottom-up approach in the project design process. However, the degree of flexibility within this approach is subject to debate. Some scholars argue that communities suffer when the construction process does not follow a bottom-up strategy (Andersen and Lyhne, 2022). Nevertheless, fully self-managed and resident-driven design and construction processes are nearly unachievable in many countries due to the current economic challenges. In the United States, where cohousing was previously resident-led (Williams, 2008), it is now often characterized by partnerships with professional developers (Fromm, 2000a). In Sweden- one of the countries with the highest building costs-cohousing has recently emerged primarily in the form of rental units provided by private companies or municipalities (Caldenby, 2021).

Up until now, research within the design cluster frequently reports that social benefits are associated with the evolution of architectural processes in cohousing. The following studies focus on social architecture design concepts in the context of cohousing. Social architecture principles refer to the incorporation of various social needs into architectural design. For instance, the Danish model's most crucial element—the dining routine—is equally significant in Malaysia. However, due to additional cleaning requirements, cleaning staff are hired to address this issue (Bin Hashim et al., 2021). In contrast to Denmark, which typically features low-rise, dense, and rural communities, Sweden practices cohousing primarily in multi-story apartment complexes (Blomberg and Kärnekull, 2019; Larsen, 2019; Caldenby, 2021; Jakobsen and Larsen, 2018). Through an interactive approach with Swedish architects, Yahia et al. (2023) examined the potential for successful cohousing in the United Arab Emirates and discussed the culturally significant balance between privacy and social contact. Their study concluded that the courtyard-type home, a traditional local architectural form, would be a suitable typology for the region (Yahia et al., 2023). Cohousing communities often include shared spaces such as guest rooms, kitchens, dining rooms, workshops, bicycle clubs, laundry facilities, gardens, and meeting rooms, depending on the level of collectivity. Numerous studies have examined the physical factors that influence social interaction, including parking lot layout (Ruiu, 2016; Williams, 2005a; Fromm, 2000a), size (De Jorge-Huertas and De Jorge-Moreno, 2024; Ledent, 2021; Griffith et al., 2024; Williams, 2005a), acoustics (Lenel et al., 2020; Marcus, 2000; Fromm, 2000a), and site selection (Nayak et al., 2023). Zhang (2020) analyzed a failed social sustainability project in China and identified several architectural flaws, including insufficient garden spaces, overly small private apartments, and an unsuitable height-to-distance ratio. These studies report that architects play a role in facilitating social interaction, which is frequently cited in the literature as an important objective of cohousing. In their analysis of the Danish model, McCamant and Durrett (2011) investigated physical characteristics such as size, density, and distance to ensure conditions of social interaction, aiming to determine the optimal numbers. These investigations have demonstrated that rational measurements can be applied to the relational dimension of space to enhance social contact.

Gender

There are two groups of studies within this cluster: The first group conceptualizes the ethics of care and its relationship to commoning (Wankiewicz, 2015; Arrigoitia et al., 2023), while the second group looks at the history of cohousing, which has been described in the literature as having a feminist orientation and is linked to efforts to address the gendered division of labor (Horelli, 2013; Vestbro and Horelli, 2012; Jarvis, 2011; Toker, 2010).

The gendered division of labor is reinforced by the dichotomies such as individual/society, public/private, female/male, and reason/nature, resulting in a geographical separation of work and care. Linking places and works requires an "intermediary level" of space. By creating spaces between the public and private spheres, cohousing alters the dynamics of daily life (Horelli, 2013). The intermediate space-whether a room, neighborhood, or residence-is a spatial phenomenon that serves both as a place of activity and as a generator of meaning (Saarikangas and Horelli, 2018). Toker (2010) reports that women living in cohousing communities perform less housework compared to other housing types, resulting in a reduced domestic workload. Jarvis (2011) suggests that cohousing enables residents to engage in self-directed activities and reciprocal learning, rather than framing reduced domestic work and increased leisure time as solutions to consumerism and burnout.

According to Arbell (2023), communication is a dynamic process that both reflects and reproduces social situations. The concept of commoning is strongly tied to economics, promoting collectivization in opposition to the capitalist logic of commodification and individualization. Advocates of care as a commons argue that cohousing also resists capitalism by creating shared resources and fostering communal practices (Savini, 2023). Social and spatial segregation arises when certain groups in society have their rights and responsibilities removed or imposed upon them, making sustainability more challenging to achieve. According to Arrigoitia et al. (2023), cohousing challenges traditional notions of employment and social norms, influencing social relationships and community dynamics.

DISCUSSION

This review maps the existing literature to explore the impact of cohousing. The impact areas were examined to determine the breadth of the topic—specifically which disciplines, sectors, and social spheres it influences—and to assess the extent of its effects. This process involves understanding the relevance of the study not only within academia but also in practice, politics, and other regions of the world. By doing so, the impact areas provide insights into both the quality (depth) and the breadth (scope) of the impacts.

The findings of this review, which systematically categorize the literature into five thematic clusters, provide a crucial lens through which to reconsider the historical development of cohousing. For instance, the prominent political and economic theme identified in the contemporary literature directly parallels the motivations of early utopian socialists and materialist feminists. Their experimental housing models, a direct response to the social and economic inequalities of the Industrial Revolution, were fundamentally aimed at creating political transformations. This historical parallel, suggesting that social and political drivers are as critical as economic ones, is particularly evident in the case of the United Kingdom. Despite a relatively high level of economic welfare, cohousing has not become widespread cohousing (Williams, 2005b; Arbell, 2023; Killock, 2014). Our findings reveal a significant paradox here: The UK has been the leading country in academic research on cohousing. This suggests that a lack of institutional support, insufficient public awareness, and high land costs may be more critical factors than economic prosperity alone. This demonstrates that the core motivations behind cohousing, from historical precedents to modern manifestations, have been deeply intertwined with sociopolitical contexts.

The second most prominent theme identified in the cohousing literature is social capital, which examines the role of cohousing in fostering sociability and social relationships. The articles reviewed show that the evolution of early communal housing models—which often relied on paid staff—towards a more collaborative, resident-led approach was instrumental in the formation of these communities. This finding directly aligns with the historical background's emphasis on building community and strengthening social bonds, a key motivation in the earliest contemporary collaborative housing approaches. While participation is a central factor in strengthening social capital, a key contribution of this study is the emphasis on informed participation. As identified in the literature, unstructured participation can carry risks related to time, energy, and financial costs, and may even lead to conflicts that damage community bonds (Brysch and Czischke, 2022). Our findings demonstrate that the greatest threat to social capital is not just the absence of participation, but its mismanagement. Informed participation, tailored to a project's specific needs, is a critical strategy to mitigate these risks and ensure the sustainability of community bonds.

The third thematic cluster focuses on resident analysis, exploring who resides in cohousing communities and their motivations for doing so. This theme directly aligns with the historical background, as the desires of early utopian socialists and materialist feminists for creating alternative living models are reflected in the contemporary motivations of cohousing residents. Resident analysis thus serves as an excellent tool for examining the modern-day reflections of these historical pursuits. A key contribution of this study is the finding that existing resident analyses in the literature are often conducted in a one-dimensional manner, which can lead to misleading assumptions. While the literature rarely considers factors such as tenure, household diversity, or institutional support, we found that when these aspects are included, the common assumptions about cohousing residents are challenged (Jakobsen and Larsen, 2018). Our study emphasizes the limitations of one-dimensional approaches and makes the inherent contradictions regarding cohousing resident profiles visible.

Another contribution of this study is to demonstrate the necessity of examining design and gender in conjunction. Feminist scholarship has long emphasized that space is not a neutral backdrop but an active agent in producing and reinforcing gendered inequalities. Yet, empirical attempts to test the intersections of design and gender remain scarce. This divergence presents a paradox: While the historical development of cohousing was fundamentally shaped by ideological movements focused on spatial and gender equality, current academic discourse often overlooks these very issues. The results suggest a need for future research to return to the foundational principles of cohousing, examining how design and gender dynamics continue to influence the success and inclusivity of these communities. The findings indicate that in cohousing, the gendered division of labor rooted in the public–private dichotomy is renegotiated through design, with "in-between spaces" emerging as critical arenas for reconfiguring identities and responsibilities. This suggests that bringing design and gender into the same analytical frame may open up a promising but underexplored line of inquiry, both theoretically and practically.

While this study's methodology was designed to be comprehensive, with searches conducted in both English and Turkish, a crucial finding is the significant scholarly gap in research on cohousing within the Turkish context. The absence of any articles on this topic, despite the inclusion of Turkish language publications in the search, highlights a clear need for future research to explore cohousing's potential and challenges in Türkiye.

The analysis addresses the question, 'What are the impacts of cohousing?' by synthesizing existing research and identifying gaps in the literature. However, what is truly important is to question what these findings mean in the context of the fundamental urban, social, and political challenges that modern society faces. In this context, cohousing represents more than just a housing alternative; it embodies a philosophical stance that challenges established ideologies.

Against the speculative housing spaces produced by political economy, cohousing reveals a mode of production beyond capitalism—a space created collectively by the community. In this sense, cohousing has the qualities of representing Henri Lefebvre's unification of 'conceived' and 'lived' space, thus forming a concrete example of Edward Soja's 'thirdspace' theory.

This 'thirdspace' is not merely a physical structure but an expression of social processes that support the bottom-up formation of social capital. In contrast to the assumption of a homogeneous community, cohousing exhibits an attitude that values and includes all differences. This approach counters segregating spatial arrangements by creating a more unifying and connective area that enables the intersection of genders.

CONCLUSION

This review maps the existing cohousing literature, revealing key thematic areas and their research intensity. Beyond simply mapping the field, it proposes a theoretical framework positioning cohousing as a philosophical stance against spatial injustice, neoliberal policies, and social isolation. The findings provide a foundational framework for new initiatives by policymakers and local governments, especially given the global housing crisis.

Although the study does not offer an in-depth analysis of cohousing in the Turkish context, it highlights a significant gap in the literature regarding this topic. By identifying key thematic areas, this research offers a clear starting point for academics and policymakers in Türkiye to explore the potential of cohousing within their unique cultural and economic landscape, rather than simply adopting models from other countries.

NOTES

[1]When the Flemish government began to encourage cohousing in 2011, the term "cohousing" gradually replaced "Central Wonnen."

[2] For further info see: Warner et al., 2020; McClatchey et al., 2023; Zapata & M. Stone, 2022; Carrere et al. 2020; Ige et al., 2018.

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Appendix: https://jag.journalagent.com/megaron/abs_files/MEGARON-02222/MEGARON-02222_(4)_MEGARON-02222_Appendix.pdf

REFERENCES

Andersen, M. A., & Lyhne, M. B. (2022). Co-creating Danish cohousing. *arq*, *26*(2), 197–208. https://doi.org/10.1017/S1359135522000355

Arbell, Y. (2022). Beyond affordability: English cohousing communities as white middle-class spaces. *Housing Theory and Society*, *39*(4), 442–463. https://doi.org/10.1080/14036096.2021.1998217

Arbell, Y. (2023). The circle of commoning: Conceptualising commoning through the case of community-led housing. *International Journal of the Commons*, *17*(1), 228–242. https://doi.org/10.5334/ijc.1210

Arrigoitia, M. F., & Tummers, L. (2019). Cohousing professionals as 'middle-agents': Perspectives from the UK, USA and the Netherlands. *Built Environment*, *45*(3), 346–363.

Arrigoitia, M. F., Ferreri, M., Hudson, J., Scanlon, K., & West, K. (2023). Toward a feminist housing commons? Conceptualising care - (as) - work in collaborative housing. *Housing Theory and Society*, *40*(5), 660–678. https://doi.org/10.1080/14036096.2023.2247414

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology*, *8*, 19–32.

Beck, A. F. (2020). What is co-housing? Developing a conceptual framework from the studies of Danish intergenerational co-housing. *Housing Theory and Society*, *37*(1), 40–64. https://doi.org/10.1080/14036096.2019.1633398

Berg, P., Wielen, K., Maussen, S., & Arentze, T. (2020). A path analysis of factors influencing social cohesion and neighbor support in collective selfbuild housing: The importance of getting to know future neighbors. *Journal of Housing and the Built Environment*, *36*, 965–989. https://doi.org/10.1007/s10901-020-09807-8

Berggren, H. M. (2020). Is cohousing good for democracy? Comparing political participation among residents of cohousing communities and traditional condominium developments. *Housing and Society, 47*, 189–214. https://doi.org/10.1080/08882746.2020.1778991

Bin Hashim, M. Z., Awaluddin, Z. A., A M R, A., Sarkum, S. A., Sholih, A. B., Aziz, A. A. (2021). Architectural design in rethinking the future of co-housing in Malaysia. *Journal of Design Built Environment*, *21*(3), 83–94. https://doi.org/10.22452/jdbe.vol21no3.6

Blandy, S. (2023). The properties of self-managed collective housing, kinning, and inheritance. *Social Anthropology/Anthropologie Sociale*, *31*(3), 68–83. https://doi.org/10.3167/saas.2023.310306

Blomberg, I., & Kärnekull, K. (2019). Do-it-yourself: The stony road to cohousing in Sweden. *Built Environment*, *45*(3), 280–295. https://doi.org/10.2148/benv.45.3.280

Boonstra, B. (2016). Mapping trajectories of becoming: Four forms of behaviour in co-housing initiatives. *TPR*, *87*(3), 275–295. https://doi.org/10.3828/tpr.2016.20

Bossuyt, D. (2021). Who owns collaborative housing? A conceptual typology of property regimes. *Housing Theory and Society*, *39*, 200–216. https://doi.org/10.1080/14036096.2021.1888788

Bossyurt, D., Salet, W., & Majoor, S. (2018). Commissioning as the cornerstone of self-build: Assessing the constraints and opportunities of self-build housing in the Netherlands. *Land Use Policy*, *77*, 524–533.

Boyer, R. H. W., & Leland, S. (2018). Cohousing for whom? Survey evidence to support the diffusion of socially and spatially integrated housing in the United States. *Housing Policy*, *28*(5), 653–667. https://doi.org/10.1080/10511482.2018.1424724

Bresson, S., & Denèfle, S. (2015). Diversity of self-managed co-housing initiatives in France. *Urban Research & Practice*, *8*(1), 5–16. https://doi.org/10.1080/17535069.2015.1011423

Brysch, S. L., & Czischke, D. (2022). Affordability through design: The role of building costs in collaborative housing. *Housing Studies*, *37*(10), 1800–1820. https://doi.org/10.1080/02673037.2021.2009778

Brysch, S. L., Mateu, A. G., & Czischke, D. (2023). The process of value setting through co-design: The case of La Borda, Barcelona. *CoDesign, 20*(3), 405–421. https://doi.org/10.1080/15710882.2023.2277724

Caldenby, C. (2021). Kollektivhus: The Swedish model. *Docomomo*, 65(2), 92–97.

Carrere, J., Reyes, A., Oliveras, L., Fernández, A., Peralta, A., Novoa, A. M., Pérez, K., & Borrell, C. (2020). The effects of cohousing model on people's health and wellbeing: A scoping review. *Public Health Reviews*, *41*, 22. https://doi.org/10.1186/s40985-020-00138-1

Chatterton, P. (2013). Towards an agenda for post-carbon cities: Lessons from Lilac, the UK's first ecological, affordable cohousing community. *International Journal of Urban and Regional Research*, *37*(5), 1654–1674.

Chiodelli, F., & Baglione, V. (2013). Living together privately: For a cautious reading of cohousing. *Urban Research & Practice, 7*(1), 20–34. http://dx.doi.org/10.1080/17535069.2013.827905

Cortés-Urra, V., Ersoy, A., Czischke, D., & Gruis, V. (2023). The potential of collaborative housing to tackle the social deficit of housing: The Chilean case. *Journal of Housing and the Built Environment, 39,* 697–725. https://doi.org/10.1007/s10901-023-10094-2

Czischke, D. (2018). Collaborative housing and housing providers: Towards an analytical framework of multi-stakeholder collaboration in housing co-production. *International Journal of Housing Policy*, *18*(1), 55–81. https://doi.org/10.1080/19491247.2017.1331593

De Jorge-Huertas, V. (2020). Collaborative designing of communities. Helsinki and Zurich pioneers. *ACE: Architecture, City and Environment*, *15*(43), 9012. http://dx.doi.org/10.5821/ace.15.43.9012

De Jorge-Huertas, V., & De Jorge-Moreno, J. (2024). Typology and interiority of cohousing in Europe 1981–2021. *Interiority*, *7*(1), 79–100. https://doi.org/10.7454/in/v7i1.317

DeVos, E., & Spoormans, L. (2022). Collective housing in Belgium and the Netherlands: A comparative analysis. *Urban Planning*, *7*(1), 336–348. https://doi.org/10.17645/up.v7i1.4750

Droste, C. (2015). German co-housing: An opportunity for municipalities to foster socially inclusive urban development?. *Urban Research & Practice*, *8*(1), 79–92. https://doi.org/10.1080/17535069.2015.1011428

Fromm, D. (2000a). American cohousing: The first five years. *Journal of Architectural and Planning Research*, *17*(2), 94–109.

Fromm, D. (2000b). Introduction to the cohousing issue. *Journal of Architectural and Planning Research*, *17*(2), 91–93.

Garcia, D. (2023). Collaborative housing: Mutual aid, cooperatives, and participation in public promotion policies for housing. *Arquit*, *41*(64), 22–37. https://doi.org/10.22320/07196466.2023.41.064.02

Griffith, E. J., Jepma, M., & Savini, F. (2024). Beyond collective property: A typology of collaborative housing in Europe. *International Journal of Housing Policy*, *24*(1), 121–141. https://doi.org/10.1080/19491247.2022.2123272

Hardy, D. (1979). *Alternative communities in nineteenth century England* (1st ed.). Longman.

Hayden, D. (1977). *Seven American utopias: The architecture of communitarian socialism, 1790–1975*. MIT.

Hayden, D. (1978). Two utopian feminists and their campaigns for kitchenless houses. *Signs*, *4*(2), 274–290.

Hayden, D. (1981). *The grand domestic revolution: A history of feminist designs for American homes, neighborhoods and cities*. MIT.

Holtzman, G. (2024). *Community by design, by the people: Social approach to designing and planning cohousing and ecovillage communities*. *Journal of Green Building*, *9*(3), 60–82.

Horelli, L. (2013). The role of shared space for the building and maintenance of community from the gender perspective: A longitudinal case study in a neighbourhood of Helsinki. *Social Sciences Directory*, *2*(3), 1–20.

Horňáková, M., & Jíchová, J. (2020). Deciding where to live: Case study of cohousing-inspired residential project in Prague. *Journal of Housing and the Built Environment*, *35*, 807–827. https://doi.org/10.1007/s10901-019-09714-7

Ige, J., Pilkington, P., Orme, J., Williams, B., Prestwood, E., Black, D., &Scally, G. (2018). The relationship between buildings and health: A systematic review. *J Public Health, 41*(2), e121–e132.

Jakobsen, P., & Larsen, H. G. (2018). An alternative for whom? The evolution and socio-economy of Danish cohousing. *Urban Research & Practice, 12*(4), 414–430. https://doi.org/10.1080/17535069.2018.1465582

Jarvis, H. (2011). Saving space, sharing time: Integrated infrastructures of daily life in cohousing. *Environment and Planning*, *43*, 560–577.

Jarvis, H. (2013). Against a tyranny of single-family. *International Planning Studies*, *10*(2), 145–177.

Jarvis, H., & Bonnett, A. (2013). Progressive nostalgia in novel living arrangements: A counterpoint to neo-traditional new urbanism? *Urban Studies*, *50*(11), 2349–2370. https://doi.org/10.1177/0042098013478235

Jarvis, H. (2015). Towards a deeper understanding of the social architecture of co-housing: Evidence from the UK, USA and Australia. *Urban Research & Practice*, *8*(1), 93–105. https://doi.org/10.1080/17535069.2015.1011429

Kehl, K., & Then, V. (2013). Community and civil society returns of multi-generation cohousing in Germany. *Journal of Civil Society*, *9*(1), 41–57. https://doi.org/10.1080/17448689.2013.771084

Korpela, S. (2012). Casa Malta: A case study of a contemporary co-housing project in Helsinki. *Built Environment*, *38*(3), 336–344.

Kvietkute, D., & Hauge, A. L. (2022). Living with strangers: Exploring motivations and stated preferences for considering co-housing and shared living in Bergen, Norway. *Housing and Society*, *49*(2), 128–149. https://doi.org/10.1080/08882746.2021.1972264

Laine, M., Helamaa, A., Kuoppa, J., & Alatalo, E. (2018). Bricolage in collaborative housing in Finland: Combining resources for alternative housing solutions. *Housing Theory and Society*, *37*(1), 101–117. https://doi.org/10.1080/14036096.2018.1492438

Lang, R., Carriou, C., & Czischke, D. (2018). Collaborative housing research (1990–2017): A systematic review and thematic analysis of the field. *Housing Theory and Society*, *37*(1), 10–39. https://doi.org/10.1080/14036096.2018.1536077

Lang, R., & Stoeger, H. (2018). The role of the local institutional context in understanding collaborative housing models: Empirical evidence from Austria. *International Journal of Housing Policy*, *18*(1), 35–54. https://doi.org/10.1080/19491247.2016.1265265

Larsen, H. G. (2019). Three phases of Danish cohousing: Tenure and the development of an alternative housing form. *Housing Studies*, *34*(8), 1349–1371. https://doi.org/10.1080/02673037.2019.1569599

Ledent, G. (2021). Size matters: How does the number of dwellings affect housing coproduction? *Journal of Housing and the Built Environment*, *37*, 889–907. https://doi.org/10.1007/s10901-021-09863-8

Lenel, E., Demonty, F., & Schaut, C. (2020). Contemporary cohousing experiments in the Brussels-Capital Region. *The e-journal for academic research on Brussels*, *2020*, 142. https://doi.org/10.4000/brussels.4207

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: Advancing the methodology. *Implementation Science*, *5*, 69. https://doi.org/10.1186/1748-5908-5-69

Lietaert, M. (2010). Cohousing's relevance to degrowth theories. *Journal of Cleaner Production*, *18*(6), 576–580. https://doi.org/10.1016/j.jclepro.2009.11.016

Marcus, C. C. (2000). Site planning, building design, and a sense of community: An analysis of six cohousing schemes in Denmark, Sweden, and the Netherlands. *Journal of Architectural and Planning Research*, *17*(2), 146–163.

Markle, E. A., Rodgers, R., Sanchez, W., & Ballou, M. (2015). Social support in the cohousing model of community: A mixed-methods analysis. *Community Development*, *46*(5), 616–631. https://doi.org/10.1080/15575330.2015.1086400

Meltzer, G. (2000). Cohousing: Verifying the importance of community in the application of environmentalism. *Journal of Architectural and Planning Research*, *17*(2), 110–132.

Meltzer, G. (2006). *Sustainable community: Learning from the cohousing model*. Trafford.

McCamant, K., & Durrett, C. (1988). *Cohousing – A contemporary approach to housing ourselves*. Habitat Press/Ten Speed Press.

McCamant, K., & Durrett, C. (2011). *Creating cohousing: Building sustainable communities* (1st ed.). New Society Publishers.

McClatchey, R., McClymont, K., Griffin, E., & Carmichael, L. (2023). Community led housing, health, and wellbeing: A comprehensive literature review. *International Journal of Housing Policy, , 25*(1), 18–55. https://doi.org/10.1080/19491247.2023.2232200

Moradi, M., & Hoseini, A. (2022). The rural texture of Azghad village: Historical context of collective housing. *International Journal of Rural Management*, *18*(2), 289–310.

Nayak, S. R., Dash, S. P., Amin, P. S., & Priyashantha, K. G. (2023). A review on intergenerational cohousing: A possible living option for elderly and youth. *New Design Ideas*, *7*(3), 535–556.

Putnam, R. D. (2000). *Bowling alone: The collapse and revival of American community*. Simon & Schuster.

Put, B., & Pasteels, I. (2022). Motivational barriers to shared housing: The importance of meanings of "home" in the diffusion of housing innovations. *Housing Theory and Society*, *39*(3), 257–274. https://doi.org/10.1080/14036096.2021.1932580

Ruiu, M. L. (2014). Differences between cohousing and gated communities: A literature review. *Sociological Inquiry*, *84*(2), 316–335. https://doi.org/10.1111/soin.12031

Ruiu, M. L. (2016). The social capital of cohousing communities. *Sociology*, *50*(2), 400–415.

Ruiu, M. L. (2017). Participatory processes in designing cohousing communities: The case of the community project. *Housing and Society*, *43*(3), 168–181. https://doi.org/10.1080/08882746.2017.1363934

Saarikangas, K., & Horelli, L. (2018). Modern home, environment, and gender: Built, planned, and lived spaces in post-war Finland. In A. Staub (Ed.), *The Routledge companion to modernity, space and gender* (1st ed.). Routledge.

Sanguinetti, A. (2014). Transformational practices in cohousing: Enhancing residents' connection to community and nature. *Journal of Environmental Psychology*, *40*, 86–96. https://doi.org/10.1016/j.jenvp.2014.05.003

Sanguinetti, A., & Hibbert, K. (2018). More room for cohousing in the United States: Understanding diffusion potential by exploring who knows about, who likes, and who would consider living in cohousing. *Housing and Society*, *45*(3), 139–156. https://doi.org/10.1080/08882746.2018.1529507

Savini, F. (2023). Maintaining autonomy: Urban degrowth and the commoning of housing. *Urban Studies*, *60*(7), 1231–1248. https://doi.org/10.1177/00420980221121517

Scheller, C., & Thörn, H. (2018). Governing 'sustainable urban development' through self-build groups and co-housing: The cases of Hamburg and Gothenburg. *International Journal of Urban and Regional Research*, *42*, 914–933. https://doi.org/10.1111/1468-2427.12652

Schelisch, L., Spellerberg, A., & Vollmer, M. (2019). The cooperative as legal form for cohousing projects in the German state of Rhineland-Palatinate: A status report. *Built Environment*, *45*(3), 388–401.

Schetsche, C., Jaume, L. C., Gago-Galvagno, L., & Elgier, A. M. (2021). Living in cohousing communities: Personality traits and trait emotional intelligence. *European Journal of Mental Health*, *16*(2), 170–183. https://doi.org/10.5708/EJMH.16.2021.2.8

Thankamoniyan, N. M., & Jagadisan, S. (2021). Enhancing oneness through a co-housing community. *Space and Culture*, *9*(1), 111–137. https://doi.org/10.20896/saci.v9i1.1126

Toker, Z. (2010). New housing for new households: Comparing cohousing and new urbanist developments with women in mind. *Journal of Architectural and Planning Research*, *27*(4), 325–333.

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., Lewin, S., Godfrey, C. M., Macdonald, M. T., Langlois, E. V., Soares-Weiser, K., Moriarty, J., Clifford, T., Tunçalp, Ö., & Straus,

S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine*, *169*, 467–473.

Tummers, L. (2015). Understanding co-housing from a planning perspective: Why and how? *Urban Research & Practice*, *8*(1), 64–78. https://doi.org/10.1080/17535069.2015.1011427

Tummers, L. (2019). Beyond wishful thinking: A FPE perspective on commoning, care, and the promise of co-housing. *International Journal of the Commons*, *13*(1), 62–83. https://doi.org/10.18352/ijc.918

Vestbro, D. U. (1992). From central kitchen to community co-operation: Development of collective housing in Sweden. *Open House International*, *17*(2), 30–38.

Vestbro, D. U. (2000). From collective housing to cohousing — A summary of research. *Journal of Architectural and Planning Research*, *17*(2), 164–178.

Vestbro, D. U. (2010, May 5–9). *Living together–Cohousing ideas and realities around the world*. Proceedings from the international collaborative housing conference in Stockholm, 5–9 May 2010). Stockholm, Sweden.

Vestbro, D. U., & Horelli, L. (2012). Design for gender equality: The history of co-housing ideas and realities. *Built Environment*, *38*(3), 315–335.

Wang, J., Pan, Y., & Hadjri, K. (2020). Social sustainability and supportive living: Exploring motivations of British cohousing groups. *Housing and Society*, *48*(1), 60–86. https://doi.org/10.1080/08882746.2020.1788344

Wankiewicz, H. (2015). The potential of cohousing for rural Austria. *Urban Research & Practice*, *8*(1), 46–63. https://doi.org/10.1080/17535069.2015.1011426

Warner, E., Sutton, E., & Andrews, F. (2020). Cohousing as a model for social health: A scoping review. *Cities & Health, 8*(1), 107–119. https://doi.org/10.1080/23748834.2020.1838225

Williams, J. (2005a). Designing neighbourhoods for social interaction: The case of cohousing. *Journal of Urban Design*, *10*(2), 195–227. https://doi.org/10.1080/13574800500086998

Williams, J. (2005b). Sun, surf, and sustainable housing: Cohousing, the Californian experience. *International Planning Studies*, *10*(2), 145–177.

Williams, J. (2008). Predicting an American future for cohousing. *Futures*, *40*, 268–286. https://doi.org/10.1016/j.futures.2007.08.022

Yahia, M. W., Mushtaha, E., Yassin, S. A., AlFoudari, K. A., Atoum, Y. A., Opoku, A., Dirar, S., & Maksoud, A. M. (2023). Cohousing design guidelines for better social integration in the United Arab Emirates. *Frontiers in Built Environment*, *9*, 1155179. https://doi.org/10.3389/fbuil.2023.1155179

Zapata, N. A. G., & Wendy, M. S. (2022). Home motivations and lived experiences in housing cooperatives and cohousing communities: A two-contexts scoping review. *Housing Studies, 39*(8), 1974–1997. https://doi.org/10.1080/02673037.2022.2157801

Zhang, D. (2020). Shilinyuan New Courtyard-Garden Housing in Suzhou: Residents' experiences of the redevelopment. *Journal of Chinese Architecture and Urbanism*, *2*(1), 1–20. https://doi.org/10.36922/jcau.v2i1.530

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Article

Retrofitting vernacular screens in contemporary facades in hot and dry regions: A climate control study using energy and CFD simulations

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ABSTRACT

This research examines the perforated geometric screens (jaali, also called mashrabiya) extensively used in Islamic and Indo-Islamic architecture. Historically, these elements have been used not only for aesthetic purposes but also as passive design strategies to regulate indoor temperature through natural ventilation and shading. This study hypothesizes that the principles of traditional jaali can be reinterpreted and integrated into contemporary facade design to improve thermal comfort, particularly in hot and dry climates. To test this hypothesis, the research used a conceptual case study of the Kilis Resource and Community Center (KRCC) in Türkiye. The study assessed internal airflow patterns and thermal conditions using energy modeling and Computational Fluid Dynamics (CFD) simulations via the IESVE software. The analysis was done during the cooling period, with two representative summer days: May 3rd and July 15th. Results showed that all investigated ventilation scenarios with jaali-integrated facades had lower indoor temperatures throughout the day. However, the presence of open windows was crucial to maintain indoor temperatures below outdoor levels, allowing air movement. The findings suggest that using jaalis in hot climates should be encouraged, as it lowered temperatures by up to 2°C during the cooling season with the help of natural ventilation.

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INTRODUCTION

Recent studies underscore the urgent need to address global warming and its environmental consequences (IPCC, 2022; Mofolasayo, 2022; Santos et al., 2022). Achieving sustainable development requires both mitigation to address the root causes of climate change and adaptation to minimize its impacts (Tol, 2005). The construction sector contributes nearly 39% of global energy-related CO_2 emissions- 28% from building operations and 11% from materials production and construction activities- and accounts for approximately 40% of annual global energy consumption, largely due to heating and cooling demands (Fumo, 2014; He et al., 2019; Simonen et al., 2017; Song et al., 2021; UN report, 2020; UNEP, 2009). To reduce operational energy use, research increasingly emphasizes passive design strategies such as natural ventilation, which can lower emissions and improve thermal comfort (Liu et al., 2023; Song

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et al., 2021). Unlike energy-intensive mechanical systems, natural ventilation leverages outdoor airflows and pressure differences, though its effectiveness depends on local wind patterns, climate, building orientation, form, and façade design (Ohba & Lun, 2010).

Vernacular Screens and Contemporary Facades

In response to the growing demand for sustainable and energy-efficient building designs, researchers have explored various retrofit strategies to improve the performance of existing building stock. The International Energy Agency (IEA) estimates that 20% of all buildings must be retrofitted with energy efficiency measures by 2030 to reach a net-zero emission goal by 2050 (Song et al., 2021). These retrofits aim to improve passive climate control within buildings, thereby reducing the reliance on active systems such as air conditioning (Liu et al., 2023).

One widely studied approach is the integration of vernacular screens into contemporary facades (Aflaki et al., 2015; Sarihi et al., 2021). Vernacular screens, also known as 'jaalis' or 'mashrabiyas', are traditional sun shading devices used in Islamic architecture for centuries to regulate heat gain and enhance ventilation (Du et al., 2019) when providing privacy (Figure 1). Historically, these screens were constructed from locally sourced materials such as stone, clay, wood, bamboo, or metal, tailored to the regional climate. Strategically positioned on exterior walls, their intricate geometric patterns not only enhanced the aesthetics of buildings but also reduced interior heat gain by blocking direct sunlight while allowing airflow (Du et al., 2019; Elzeyadi & Batool, 2017).

Natural ventilation occurs due to pressure differences created by wind acting on building surfaces and by temperature variations between indoor and outdoor air (El Semary et al., 2017). In Mughal architecture, controlled airflow and temperature regulation were achieved through building orientation, appropriately sized and proportioned openings, ventilated domes, and extensive use of jaali (Ali, 2013) (Figure 1b). The ventilated domes utilized the stack effect, whereby hot air inside the building rises and exits through dome openings, simultaneously inducing the airflow of cooler air from below.

Integrating vernacular screens into contemporary facades allows designers to combine traditional passive strategies with modern techniques, improving thermal performance and reducing the need for mechanical cooling. Sherif et. al (2010) showed in their research that lightweight screens with a 70-85% perforation ratio and 1:1 depth profile improved energy performance in residential buildings in hot-moderate climates, reducing solar heat gains, and enhancing thermal comfort (Sherif et al., 2012a). Originally developed for residential use, these screens are increasingly applied to diverse building typologies, including galleries and museums.

For instance, in contemporary exhibition design, traditional shading devices are reinterpreted to shape spatial atmosphere. Perforated wooden panels filter natural light,

Figure 1. The use of Jaali screen in Islamic architecture, (Left) Alhambra Palace, Spain (Photo by Author, (Right) Lahore Fort, Pakistan.

casting patterned projections across floors and walls, moderating glare, reducing solar heat gain, and regulating the interior thermal environment. Simultaneously, the intricate perforations fragment daylight into shifting patterns, creating a dynamic visual experience that enhances visitor engagement (Figure 2). In museum contexts, this reinterpretation connects contemporary spaces to architectural traditions while enriching the atmosphere with distinct aesthetic qualities. For example, carved walnut screens by Ahmad Angawi in the British Library galleries filter light into exhibition areas, situating audiences within a dialogue between past and present (Jakeman, 2018).

These vernacular screens function on multiple levels: As climatic regulators, cultural expressions, and aesthetic elements that transform daylight into an ephemeral decorative feature within the interior environment. Previous research has shown that retrofitted screens can improve natural ventilation, shading, and daylighting, reducing reliance on mechanical cooling and artificial lighting (Du et al., 2019; El Semary et al., 2017; Elzeyadi & Batool, 2017). However, quantitative studies remain limited, particularly regarding optimal geometry, perforation ratios, and climate-specific design guidelines (Du et al., 2019). This study focuses on evaluating changes in interior climate performance resulting from retrofit designs that integrate *jaalis*.

Figure 2. Jaali screen in the British Library, London. (Photo by Author).

Objectives of this Computational Study and Research Gap

Computational studies have shown that integrating vernacular screens can enhance buildings' thermal performance and energy efficiency (Ali, 2013; Dev et al., 2021; Sherif et al., 2012a). Such simulations typically account for factors including solar radiation, wind speed, and building materials, providing valuable insights into the potential benefits and limitations of retrofitting such elements. While prior research has modeled the efficiency of shading devices like louvers (Elzeyadi & Batool, 2018), there is still a gap in studies specifically assessing the impact of retrofitted vernacular screens on indoor climate using simulation tools (Taki & Kumari, 2023).

This computational study aims to investigate the potential of retrofitting vernacular screens (jaali) into modern facades for passive climate control. Specifically, it will assess how natural ventilation affects the thermal performance of a case study building equipped with retrofitted jaalis. Various ventilation scenarios, no ventilation, natural ventilation, and stack ventilation, are analyzed to assess their effectiveness in regulating indoor temperatures and enhancing occupant comfort. By focusing on the use of vernacular screens for passive climate control in contemporary facades, this study addresses an underexplored area in sustainable building design. Through simulation-based analysis, it provides evidence-based insights to inform energy-efficient and climate-responsive architectural strategies.

Literature Review

In contemporary residential design, architects and engineers face the dual challenge of ensuring occupant thermal comfort while reducing environmental impacts. Heating, ventilation, and air-conditioning (HVAC) systems are central to this effort, as their efficiency directly influences both energy demand and greenhouse gas emissions. With climate change, periods requiring mechanical cooling are lengthening, resulting in increased energy consumption in buildings. A more sustainable alternative lies in the passive cooling strategies offer a sustainable alternative, capable of reducing environmental impacts and operational costs (Sarna & Ferdyn-Grygierek, 2025). A recent study by Iskandar et al. (2025) emphasize the necessity of adaptive retrofit strategies, leveraging existing systems, the implementation of operational modifications, and the integration of shading devices to mitigate heat gain.

The challenge posed by climate change is evident not only in hot climatic zones but also in regions with historically heating-dominated temperate climates, which experience cold winters and mild to warm summers (Berger & Worlitschek, 2019; Parker, 2021). Studies of current and projected climate scenarios indicate that global warming will reduce heating demand while increasing cooling needs (Bay-Sahin et al., 2025; Rahif et al., 2022; Wilbanks et al., 2008). Beyond energy demand, climate change also affects renewable energy reliability (Rahman et al., 2025), and increases the risk of overheating, which negatively impacts occupant comfort, (Bay-Şahin & Elnimeiri, 2025; Lan et al., 2017), productivity (Hooyberghs et al., 2017), and health (Armstrong et al., 2011). However, research in Mediterranean climates remains scarce (Chkeir et al., 2024).

In these climates, passive cooling techniques for buildings can lower indoor temperatures in warm periods with minimal energy consumption. Geetha and Velraj (2012) classified these methods into three categories: Reducing internal heat gains, managing heat through thermal storage or night ventilation, and dissipating heat via natural ventilation (including evaporative, ground, or radiative cooling). (Geetha & Velraj, 2012). Fathy (2000) observed that traditional rural buildings in Pakistan achieved thermal comfort using passive design measures, including orientation, shading, and ventilation (Fathy, 2000). Similarly, a parametric study in Portugal showed that north-facing windows performed better thermally than northwest- or northeast-facing ones (Amaral et al., 2016).

In hot climates, window shading reduces cooling loads and energy consumption by mitigating solar heat gains. For instance, field measurements in a study of a courtyard situated in a hot and dry climate demonstrated that the covered outdoor sitting area and the shading screen significantly enhanced airflow and thermal performance of the courtyard (Mohamed, 2018). A computational study of a residential building in a desert climate evaluated various perforation percentages and depths. Results show that fixed, deep perforated solar screens on the west and south facades can achieve energy savings of up to 30% of total energy use (Sherif et al., 2012b).

Effectively bridging thermal comfort and natural ventilation requires understanding air flow dynamics, as air velocity is a key determinant of occupant comfort (Wu et al., 2021). Natural ventilation, driven by wind and buoyancy, is essential for improving indoor air quality and reducing cooling energy demand. Wind-driven cross ventilation and buoyancy-driven stack ventilation are the primary strategies for achieving passive airflow (Al-Shamkhee et al., 2022). Evaluating these strategies during the design stage is therefore critical. Building energy modeling has therefore become a common tool for evaluating design decisions early in the process and predicting performance in terms of energy use or natural ventilation (Du et al., 2019; I. M. K. Elzeyadi & Batool, 2017; Ghaddar et al., 2024).

Recent work has demonstrated how traditional sun-shading elements, such as Aegean venetian blinds, can be systematically evaluated through energy simulations to assess their impact on daylight balance and cooling loads, offering insights for adapting vernacular strategies to contemporary sustainable design (Cavka & Feruz, 2022). Another study in a similar climate used building simulations to show that the geometry and placement of residential jaali screens can effectively reduce solar heat gain on south- and west-facing openings. This reduction lowered cooling loads while also improving indoor daylight distribution, highlighting their value as passive design elements in a hot-dry climate (Prasad et al., 2022). Besides common use of energy simulations, computational Fluid Dynamics (CFD) analysis has emerged as a critical tool for understanding building airflow and heat transfer. By simulating thermal buoyancy, wind-driven forces, and data analysis, CFD enables designers to visualize and optimize natural ventilation and environmental performance (Ai & Mak, 2017; Zhai, 2006).

Simulation methods, widely used in industries like chemical and aerospace engineering, help model pressure, velocity, and temperature in fluid flow processes. They are often used to verify the accuracy of those models (Elshaw et al., 2018; Palmero-Marrero & Oliveira, 2010). CFD is useful to model the physics underpinning these systems, such as the effects of thermal buoyancy, wind-driven forces, and the psychrometric properties of incoming air for more precise environmental control (Cook et al., 2003; Yao & Dang, 2023). Today, CFD plays a growing role in the building design industry, helping optimize environmental performance for energy efficiency (IESVE, n.d.; Bay et al., 2022; Capeluto & Ochoa, 2014).

CFD analysis is mostly used to assess indoor environmental conditions influenced by solar gain and airflow (Almhafdy et al., 2015). Lau et al. (2016) modeled 20 shading device configurations using IESVE software for a high-rise office in Kuala Lumpur, finding 1.0%-3.4% annual cooling energy savings depending on device type and facade orientation. Elzeyadi and Batool (2017) used IESVE to evaluate jaalis with a 30% perforation ratio across three hot climate zones. Results showed superior thermal comfort in hot-arid climates compared to hot-humid ones.

CFD has also been applied in heritage buildings to optimize ventilation. Bay et al. (2022) used IESVE and real-world monitoring to assess ventilation strategies in a historic UNESCO-listed church in San Antonio, Texas. Their study showed reduced reliance on mechanical cooling in spring, supporting natural ventilation for occupant comfort. Similarly, (Elhassan, 2023) used CFD modeling to study a residential building in a hot, dry climate, demonstrating that natural ventilation effectively maintained comfort while lowering energy use.

Overall, literature indicates that passive cooling strategies, including shading devices and natural ventilation, are essential for energy-efficient design. CFD and building energy modeling provide powerful tools for evaluating these strategies quantitatively, yet gaps remain in climate-specific applications and the integration of vernacular design elements like *jaalis* into modern buildings.

METHODS

In this study, energy and CFD analysis were combined to evaluate the applicability and efficiency of jaalis in terms of passive cooling using IES VE software. This is a building simulation tool used to create the geometry and energy model of the case study building. After determining the boundary conditions of the building on the selected dates during the cooling season, the data were used for the CFD model. This includes temperatures of opaque and transparent surfaces, heat gains and losses, and airflow rates both outside and inside the building. CFD analysis was used to investigate heat transfer processes, buoyancy effects, and wind-driven ventilation through airflow patterns. The main steps of CFD analysis in IES VE are shown in Figure 3.

All simulations done during this research took into account the entire building. Each CFD analysis was done after overall energy analyses of the KRCC building for each ventilation scenario, since each scenario was tested with and without shading devices. Also, scenarios (i) no ventilation, (ii) cross ventilation, and (iii) stack ventilation have different open/close window configurations. Since the Apache energy simulation module automatically generates the boundary conditions for a selected day and time, the data for each scenario was exported into the CFD module. Then, the CFD model settings were prepared with exported boundary conditions from the result of energy analysis. The boundary conditions file contains various data about the external conditions, such as atmospheric data, atmospheric pressure, precipitation, and moisture content, and internal conditions, such as room air temperature, surface temperature, such as wall surface temperature, and room radiant temperature.

In the IES VE MicroFlo module, a grid was created with an aspect ratio under 12:1 to provide a high level of resolution, using the recommended number of grid cells. The default turbulence model of the software was kept as the k-e turbulence model to calculate the cell's turbulent viscosity (IESVE, n.d.). CFD graphs were generated for each scenario to visualize the data provided by the energy model. The method was used to investigate the most effective natural ventilation strategy and the effect of jaalis on cooling the interior environment in the dry Mediterranean climate. The overall process followed for this research is shown in Figure 4.

Retrofitting Vernacular Screens in Modern Structures in Kilis, Türkiye

The hypothetical case study building used for this research is an unbuilt design project in Kilis, Türkiye. After the recent earthquakes in the country on February 6, 2023, this building was planned to serve as a community and resource center, Kilis Resource and Community Center (KRCC), for the affected population of Syrian refugees in the earthquake region. Kilis is located in southern Türkiye, on the border with Syria, and it is known to host the most significant number of Syrian refugees in the country. Kilis is a small city of 147,919 inhabitants (TUIK Kurumsal, n.d.). However, the vulnerable refugee population in Kilis exceeds the local populace by a ratio of 70:30.

Kilis lies 660 meters above sea level. The summers are hot and dry with sunny and clear skies, while the winters are frigid and cloudy. The temperature typically changes from 0.5°C to 35°C. Also, during the hot season that lasts for 3.5 months between mid-June and mid-September, the average daily high temperature is above 30°C. The dry season lasts 5.5 months, from May to mid-October, while the wet season lasts 6.5 months. The outdoor temperature, relative humidity, and wind velocity data are shown in Figure 5. The prevailing wind direction is west in Kilis. The KRCC building's geometry was first generated in the ModelIt module within IES VE. Precise weather data and building parameters were defined to accurately simulate the real-world scenario in a virtual environment. A weather file of the location was obtained from IES VE. This research used a Typical Meteorological Year (TMY15) file for the necessary input for the simulation process. Multiple variables in this weather file were dry bulb temperature, solar altitude and azimuth, relative humidity, direct and diffuse radiation, wind speed, and wind direction, contributing to passive climate control in buildings and reducing the reliance on mechanical means of cooling and heating.

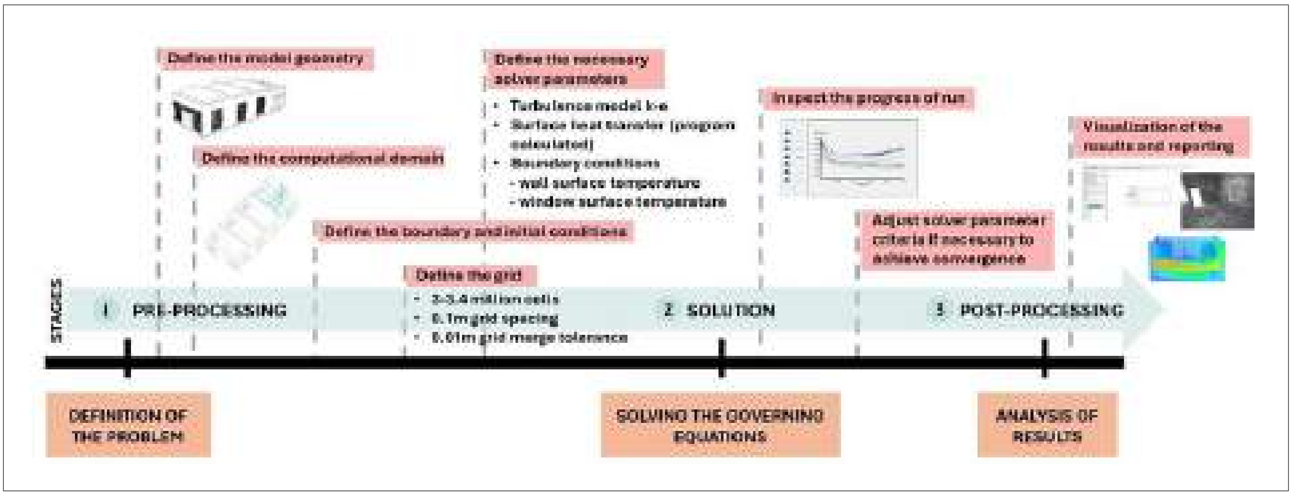

Figure 3. Main steps of CFD analysis.

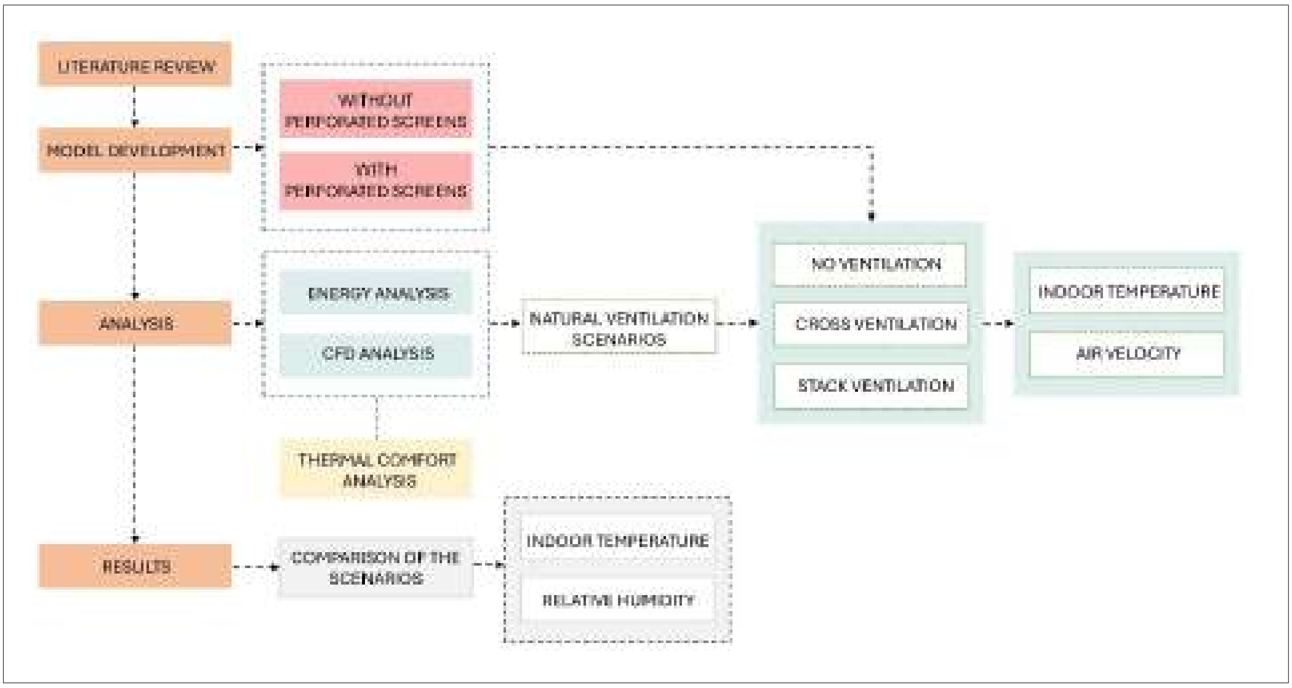

Figure 4. Applied methodology.

Case Study Building Design: KRCC

The structure was designed as a single-story building with a hall-like open office space in the south and a kitchen and bathrooms in the north. The form of the building was inspired by the metal container dwellings that have been used for housing the Syrian refugees in camps along the Türkiye-Syria border since 2011. Moreover, after the 2023 earthquake, they were used extensively in Türkiye to house the affected population in the same region, as shown in Figures 6a and 6b. The shape of the 8-meter by

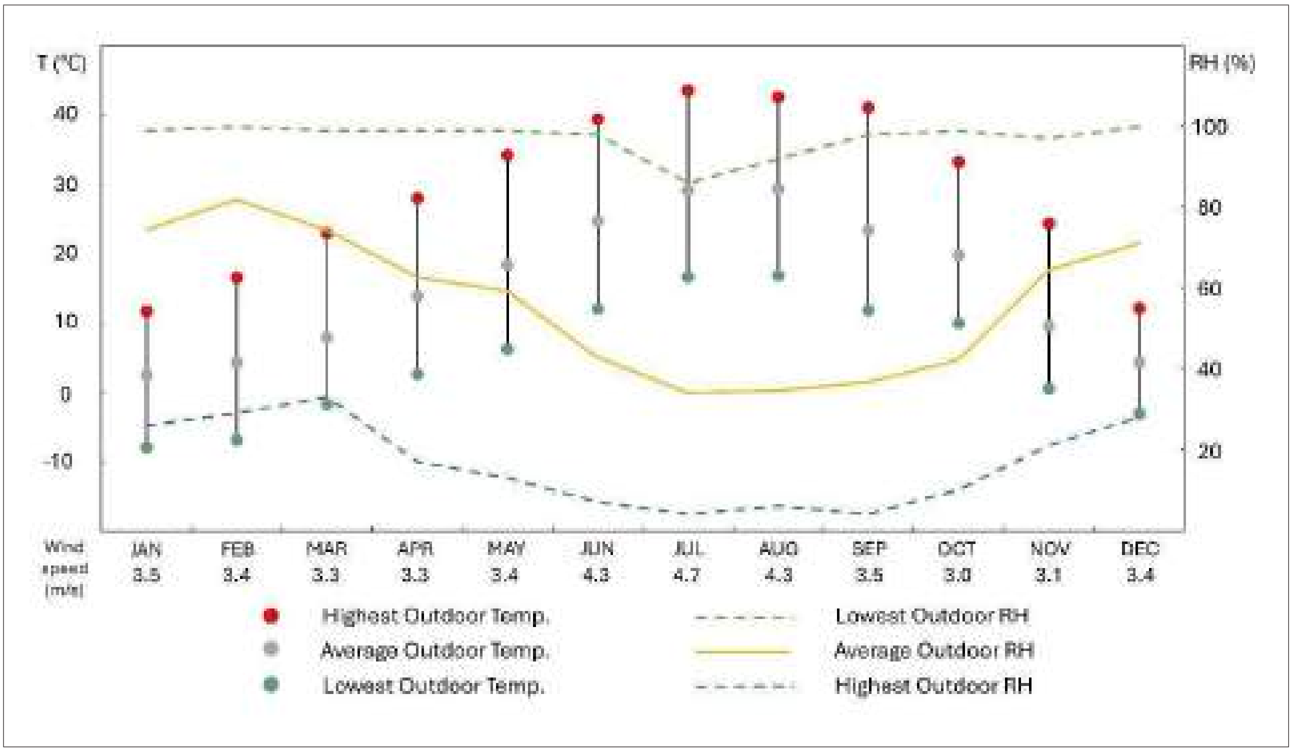

Figure 5. Outdoor temperature, relative humidity, and air velocity data for Kilis.

20-meter land parcel informed the rectangular building design shown in Figure 7.

The most problematic issues with these metal container dwellings are indoor air quality, temperature, and inefficient ventilation (Albadra et al., 2020; Wimalasena et al., 2021). During the cooling season, they become too hot, and in the winter, they become too cold because of their limited design characteristics. The KRCC building was designed as a rectangular enclosure to utilize the maximum land on the site with its long side along the north-south direction. Three triangular skylights were designed to run east-west on top of the 5.5-meter-tall building.

Window and *Jaali* Design: One essential feature of the building geometry was the window-to-wall ratio, which was determined as 21.4 % according to the ASHRAE criteria for this hot and dry climate. This value complies with the ASHRAE 90.1 standard, which recommends a WWR of less than 40% (ASHRAE, 2022). The other parameter is temperature, which affects the energy demand of buildings and the users' thermal comfort. Indoor temperatures need to be controlled, particularly in summer, when the effect of solar radiation is high. In the summer, outdoor temperatures reach more than 40°C in Kilis, making it hard to control indoor temperatures with large windows. Because of this extreme outdoor environment, the glazing designed for KRCC was kept small to minimize solar gain.

On the east, south, and west facades, side-hung operable windows were designed under the fixed horizontal windows for the main area, office, and kitchen space, as shown in Figure 7. The double-pane windows with metal frames were selected based on those commonly used by TOKI. The glass window panels can be opened towards the inside. However, the operable jaalis were designed to slide along a rail fixed on the outer side of the wall covering the window from the outside when closed (Figure 8). The bathrooms located on the northwest part of the structure had small bottom-hung windows for ventilation and natural light. To use buoyancy and bring natural light into the working space, three triangular skylights were added over the main working area, in the east-west direction. The premise for the skylights was to help the interior temperature drop by moving warm air from inside to outside through openings. The skylights provide extra daylight needed in the main hall since shading elements reduce the amount of light. The operable glazing areas were defined as 95% for side-hung windows and 30% for bottom-hung openings. Another parameter for this research was the proposed design of the shading screens, jaalis (Figure 9).

Construction Materials: When selecting construction materials for a project, it is essential to look at the local conditions, available and standard materials for affordability, and the selected materials' durability. This project took cues from the typical construction materials used in Türkiye by the governmental institution, the Mass Housing Administration (TOKI). TOKI has provided housing alternatives for the housing deficit in the country through social housing, disaster relief housing, and slum transformation projects. TOKI also builds public facilities like primary schools and neighborhood mosques (Bay, 2020). As shown in Figure 10, TOKI structures, primarily built using raft foundations, tunnel formwork, and high concrete strength, have proved durable and suitable for the region, as they withstood the two devastating 2023 earthquakes in Türkiye (Demirhan, n.d.). Thus, the KRCC building was also designed as a concrete structure.

The construction materials were selected for KRCC in the Apache module. As the typical construction material for durability and low maintenance, KRCC building walls were assumed to be made of average-weight precast concrete blocks. These blocks are formed before they are brought to the construction site. Shown in Figure 10, these

Figure 6. **a)** Container dwellings in refugee camps in Kilis, July 2022. **b)** Container dwellings shipped to Türkiye for post-earthquake emergency shelter use in the Kahramanmaraş region, April, 2023. (Photo by Authors).

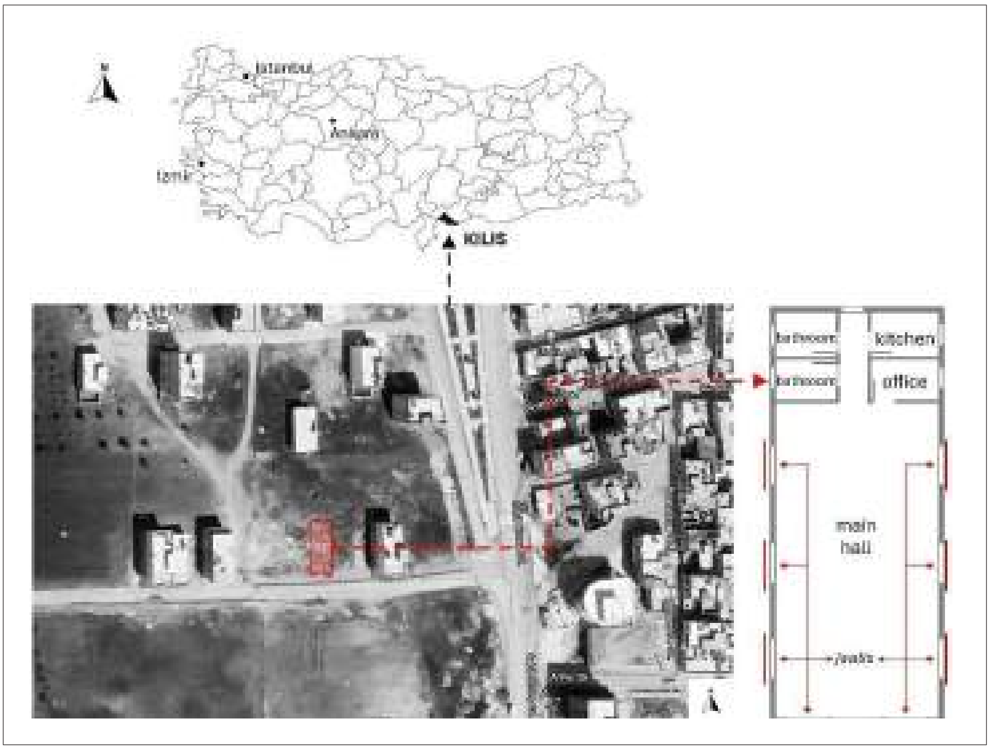

Figure 7. Proposed design of KRCC for the proposed site in Kilis. (Tapu ve Kadastro Genel Müdürlüğü, n.d.).

blocks have two hollow cavities, and they are 203 mm x 406 mm x 200 mm in size for the exterior walls and 152 mm x 406 mm x 200mm for partition walls. The materials selected for the KRCC building in the Apache module are shown in Table 1 along with the dimensions and specifications of the CFD model used in IES VE modules (ModelIt and MicroFlo). To evaluate different scenarios and understand the effect of water-resistant engineered

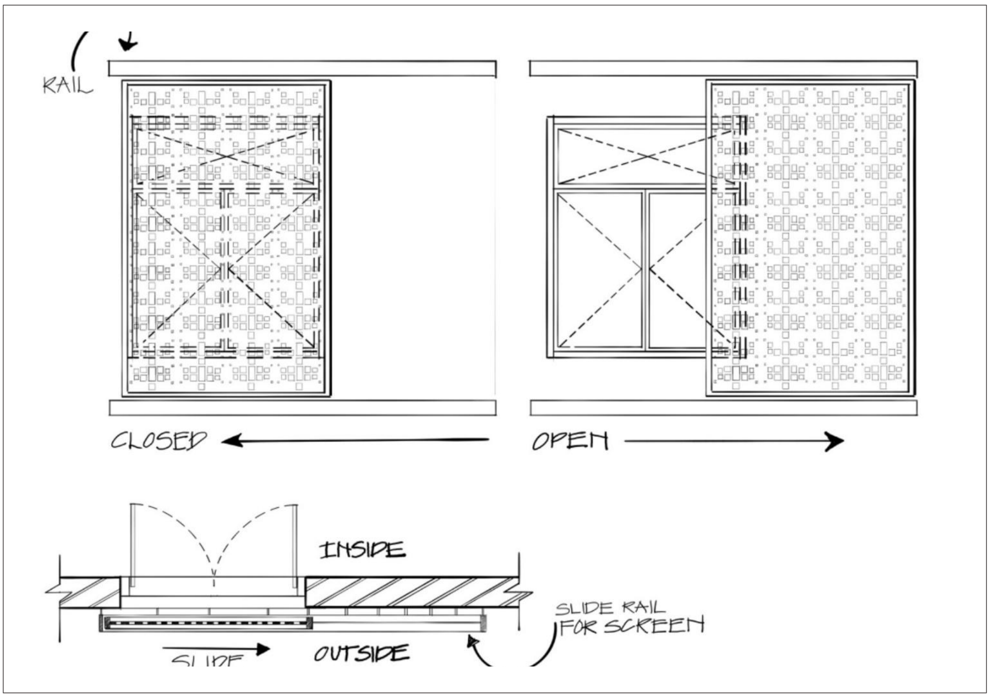

Figure 8. Operational detail of the proposed window design with jaalis for KRCC.

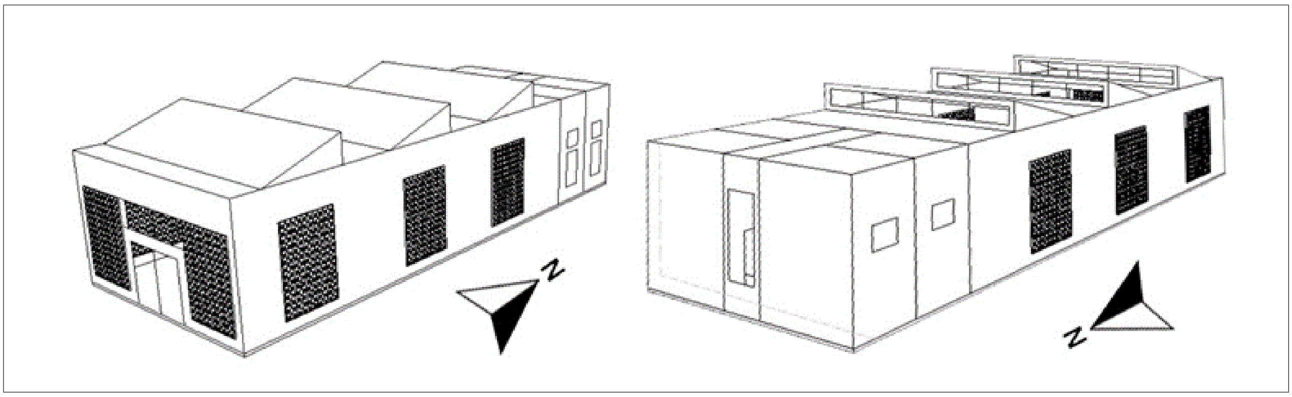

Figure 9. Proposed design with jaalis for KRCC.

wood shading screens on this structure, a 200 cm x 300 cm x 2.5 cm jaali screen was designed. The screen has two different sizes of square-shaped apertures or holes in the jaali pattern measuring 400 mm x 400 mm and 500 mm x 500 mm in size (Figure 11).

The jaali was modeled in IESVE ModelIt as water-resistant engineered wood with a thickness of 2.5 cm, as specified in the physical design. Standard thermal properties for engineered wood were assigned in the simulation. The surface color of the jaali was included indirectly by assigning a solar absorptance of 0.6, corresponding to the medium-brown color, which affects the heat gain through the screen. As shown in Figure 11, the jaali pattern included square apertures of 4 cm × 4 cm and 5 cm × 5 cm, resulting in an overall porosity of 20% (ratio 1:5). These geometrical parameters were directly incorporated in the numerical model by defining the window/shading fraction and the solar transmission through the openings, ensuring accurate representation of shading and daylight penetration.

Figure 10. Typical social housing project by TOKI in Gaziantep Türkiye.

Natural Ventilation Scenarios and Simulations

The KRCC building was tested in its free-floating state without considering any occupancy or any mechanical systems. Excluding any additional parameters such as internal loads, the study aimed to obtain a deep understanding of airflow patterns and thermal conditions. In order to determine the most appropriate passive cooling strategy, multiple natural ventilation scenarios were created, such as:

- No natural ventilation,
- Cross ventilation,
- Stack ventilation with all side and top openings.

In this study, we focused exclusively on internal CFD simulations, limiting the computational domain to the interior of the building rather than including the surrounding environment. Boundary conditions for airflow were generated from IESVE Apache simulation results using the VistaPro module and then exported to MicroFlo to analyze natural ventilation and passive cooling during the cooling season. Since MicroFlo does not have a built-in radiation model, radiation-related boundary conditions were derived automatically from the energy simulations. These included wind direction and speed, indoor and outdoor temperatures, atmospheric pressure, moisture content, as well as room air, radiant, and surface temperatures of walls and windows.

The simulations used a steady-state, three-dimensional convection–conduction model based on the finite volume meth-

Table 1. Building components used in IES VE Apache.

Building components	Material	Thickness (mm)	Conductivity (m^2K/W)
Walls*	Concrete block	200	1.6079
Partitions	Concrete block	100	0.0714
Roof	Concrete	203	1.1491
Ground floor	Concrete	380	4.3353
Windows	Double pane (metal frame)	24	0.4543

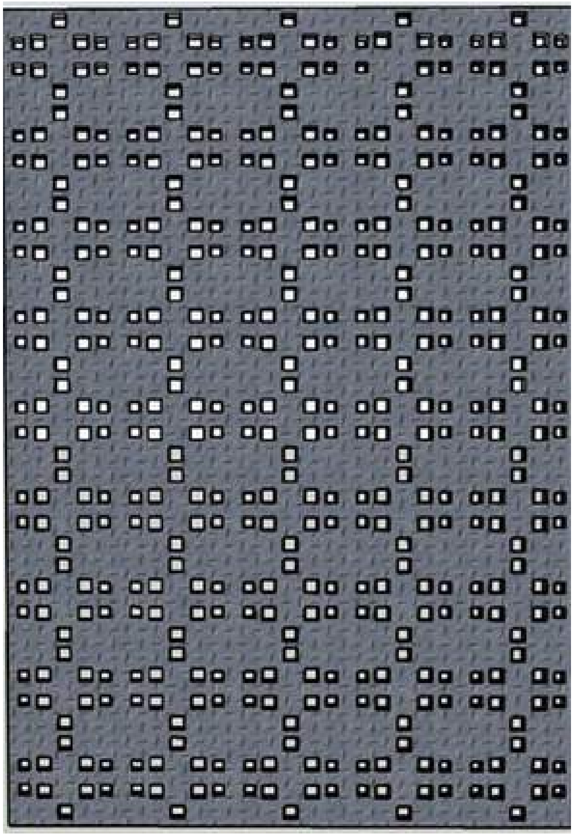

Figure 11. Proposed Jaali design for the KRCC building.

od, with the Standard k-ε turbulence model to represent turbulent airflow. The airflow in the model was aligned with the grid axes, and inlet and outlet performance was checked in MacroFlo to ensure the natural ventilation behavior was properly captured. To ensure the results were not influenced by the grid design, we performed a grid-independence study. The final mesh contained 3–3.4 million cells, providing enough detail to capture airflow patterns accurately without excessive computational cost. The mesh followed IESVE guidelines for grid spacing, cell aspect ratio (≤12:1), and grid line merge tolerance (≤0.1 m), with variable cell sizes to resolve critical areas more finely (Table 2). MicroFlo uses a structured, non-uniform Cartesian grid, which strikes a balance between accuracy and computational efficiency.

After modifying the openings based on each scenario, these models were organized into two sets. Energy and CFD simulations were run to analyze the efficiency of each. This step was repeated for two models; (i) KRCC model without jaalis (the perforated shading screens) and (ii) KRCC model with jaalis (the perforated shading screens on the main hall windows). In the first set of models, the geometry had no shading device, jaalis. In the second set, jaalis were added on the side-hung windows of the main hall on the east, south, and west facades. The vertical window brightening the corridor on the north and the triangular skylights above were used without jaalis. With the results of these simulations, indoor temperature, relative humidity, and air velocity graphs were created for two representative days of the spring and summer seasons: May 3 and July 15 at noon (Figure 12).

As shown in Table 3, the outdoor air temperature at midday was 21.4°C on May 3, rising to 32.2 °C on July 15. The external relative humidity levels at noon were 41% and 46% on May 3 and July 12, respectively. Wind speed was 3.2 m/s at noon on May 3 and 4.5 m/s on July 15. The wind direction was west during both times.

- Scenario 1 (S1): All windows were closed at all times to investigate the building without any ventilation. In this case, only air infiltration was considered. This scenario was used as a baseline model for comparison.
- Scenario 2 (S2): Cross ventilation was tested in this scenario, leaving only the east and west façade windows open. Other windows were fully closed at all times. Air infiltration was also considered.
- Scenario 3 (S3): All windows were open to allow natural ventilation and stack effect through the openings of the three triangular skylights on the top.

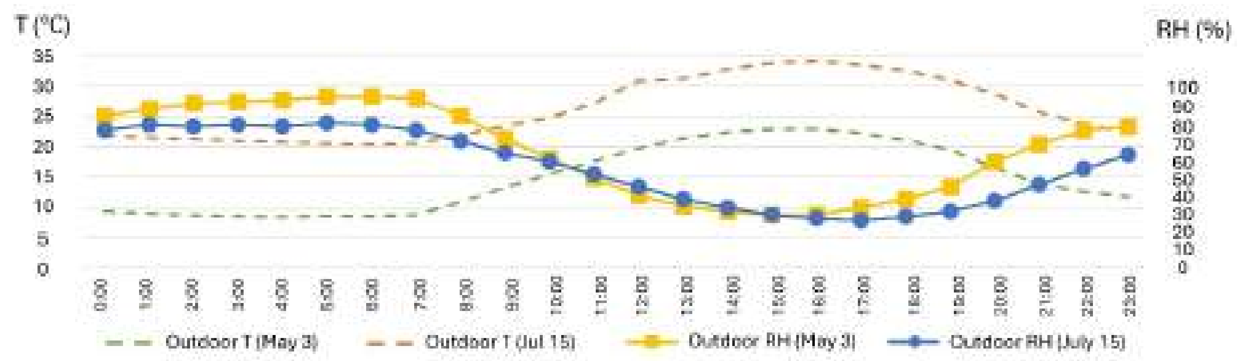

Figure 12. Outdoor conditions for selected representative days.

Table 2. Model dimensions and specifications of the CFD model (ModelIt and MicroFlo).

Building Specifications		IES VE CFD Model Specifications	
Floor surface area (m^2)	160	Number of cells (million)	3.0-3.4
Volume (m^3)	756	Max cell aspect ratio	<12:1
Ext wall area (m^2)	285	Turbulence model	k-e
Ext opening area (m^2)	61.24	Grid line merge tolerance (m)	0.01

Although all-natural ventilation scenarios only deal with open and closed window configurations with and without jaalis, the energy and CFD modeling took into account the entire building. Thus, the various temperature and velocity values were detected for each horizontal building section every 10 cm (Figure 13). The energy simulation also took into account the “unwanted” infiltration. Since the KRCC building was planned as a post-disaster structure and its construction materials were selected as typical ones used in the governmental institution TOKI, assumptions were made based on that. So, the KRCC building was considered leaky with a 2.032 l/ (s.m^2) infiltration rate, combining the experience of past studies (Hanam et al., n.d.).

FINDINGS AND DISCUSSION

The indoor temperature and velocity graphs for each scenario were generated at a height of 1 meter above the floor (Figure 13). The slices on the X and Y axes were taken from this level for each scenario to show plans and sections, respectively. The false colors from blue to red represent the temperature range from coldest to warmest. Both graphs display the average values of temperature and velocity of the horizontal slice of the floor level on May 3 and July 15.

Scenario 1 – No Natural Ventilation

Scenario 1 was used as a baseline, with all windows closed. It was analyzed without any natural ventilation except infiltration via the building envelope. The results of this scenario for air temperature and airflow for May 3rd and July 15th are displayed in Figure 14. Since indoor temperatures reached

Table 3. Airflow characteristics, indoor temperatures, relative humidity, and direct radiation.

Representative days for spring and summer	Time	Outdoor temperature (°C)	External relative humidity (%)	Velocity (m/s)	Direct radiation (W/m^2)
3-May	12:00	21.4	41	3.2	883.000
15-Jul	12:00	32.2	46	4.5	960.000

28°C and 42°C in May and July, respectively, different temperature range scales were used for this scenario (22°C-28°C for May and 36°C-42°C for July). In the cases without Jaalis, both in May and July, the temperature of the main hall was slightly higher than other spaces in the north part of the structure. Although indoor temperatures at noon dropped when perforated jaalis were added to the main hall windows, overall indoor temperatures were higher than the outdoor temperatures for both representative days.

In July, the office and bathroom 1 were cooler than other rooms, as seen in Figures 14e and g, due to their location in the northern part of the layout limited solar exposure and reduced heat accumulation. This indicates that spatial orientation has a stronger influence on indoor temperature distribution than infiltration alone. The addition of jaalis lowered indoor temperatures for each representative day by approximately 2°C by filtering direct solar radiation while still permitting some air leakage. However, since no significant air velocity was recorded, this cooling was limited to shading effects rather than active air exchange. Thus, without intentional ventilation, the building remains overheated compared to outdoor conditions, highlighting the inadequacy of infiltration-only strategies for maintaining thermal comfort.

Scenario 2 – Cross Ventilation

This scenario was analyzed with cross ventilation for prevailing winds in the west-east direction, achieved by opening windows on the west and east walls while keeping the skylight windows closed. As shown in the velocity graphs

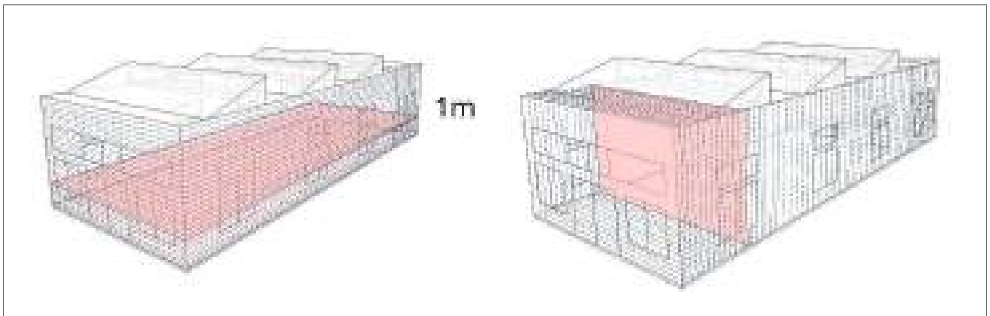

Figure 13. Horizontal and vertical slice positions for plans and sections.

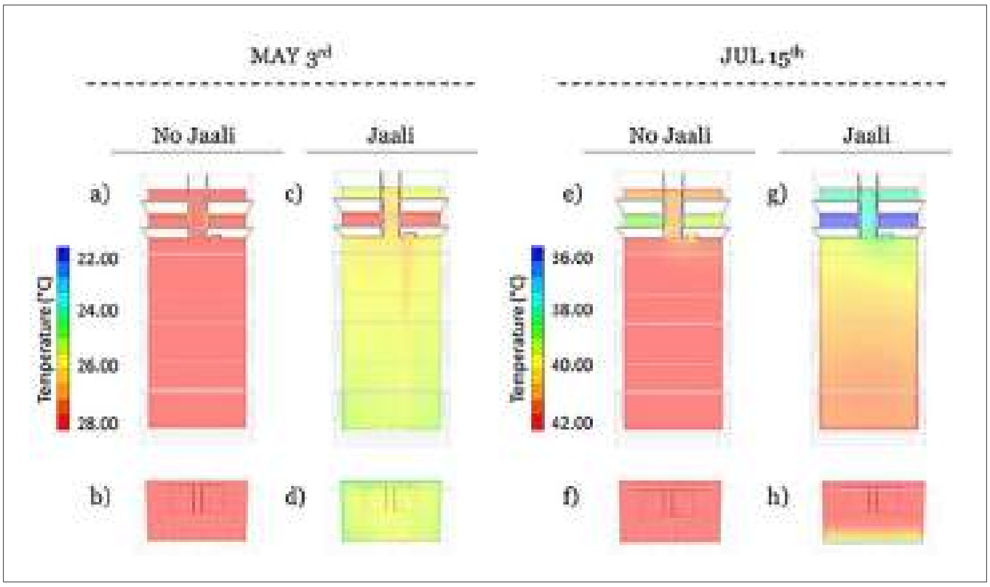

Figure 14. Air temperature distribution on the plan for Scenario 1.

in Figure 15, cross ventilation produced effective indoor airflows reaching 1.06 m/s in May and 1.3 m/s in July 15.

The higher velocities in July are directly related to stronger outdoor wind speeds, which increased the wind-driven pressure difference between the west and east façades. As a result, air entering from the west openings created a consistent airflow stream across the building. Overall, this mechanism not only reduces heat accumulation but also improves convective heat transfer from occupants' bodies, thus enhancing thermal comfort despite elevated indoor air temperatures.

The jaalis played a significant role. While they filtered solar radiation and reduced solar heat gain, they did not significantly obstruct air flow (15g and 15o). This indicated that the perforation ratio of the screens is adequate to balance shading and ventilation, making them an effective passive design element.

Moreover, thermal stratification was still evident in May with slightly higher temperatures in the west part of the building (Figure 15b). This effect can be attributed to solar exposure during the afternoon, which increased the surface temperature of west-facing walls. However, compared to Scenario 1, cross ventilation substantially improved air distribution, showing the importance of aligning openings with prevailing winds. Overall, cross ventilation harnessed wind-driven forces to generate sufficient air speeds for cooling. Although it did not always reduce indoor temperatures below outdoor levels, the increased air movement enhanced perceived comfort and prevented excessive heat in this climate.

Scenario 3 – Stack Ventilation

This scenario investigated the stack ventilation effect. To generate this scenario, all windows of the existing openings were fully open on each façade, including the bottom-hung skylight windows. In this method, hot and stagnant air in the space was forced to leave the building via the skylight windows because of temperature differences between indoor and outdoor air. Warm, buoyant indoor air rises and escapes through upper openings while cooler air is drawn in from lower openings.

Figure 16 shows the building sections. Figure 16b and 16g show that this mechanism is visible in May, where indoor hot air accumulated near the ceiling and was effectively vented through the skulight windows. Like in Scenario 2, the air movement was slower on May 3rd proportionally to the outdoor wind speed, as shown in Figure 16g and Figure 16h, reaching 0.95 m/s. On July 15th, the air movement failed to create a practical passive cooling effect since the outdoor temperatures were extremely high. Although the model with jaalis provided slightly cooler temperatures on the summer representative day, the resulting temperature was too high to reach a thermally comfortable environment for occupants. In May, the rooms with the warmest temperature in the building were those located in the northeast and northwest, while the main hall is about 2 degrees cooler, with and without jaalis. The cooler performance of the main hall highlights the effectiveness of stack-driven buoyancy when outdoor temperatures are moderate.

On the other hand, in July, the strategy failed to deliver thermal comfort. Despite the vertical airflow, the average temperature in the building is about 30°C. The reason lies in the small temperature gradient between indoor and outdoor air, since outdoor air was already extremely hot. The replacement air entering from the lower windows did not provide cooling. Instead, hot outdoor air simply replaced hot indoor air, limiting the usefulness of the stack effect. This demonstrates a key limitation of buoyancy-driven ventilation in hot summer climates.

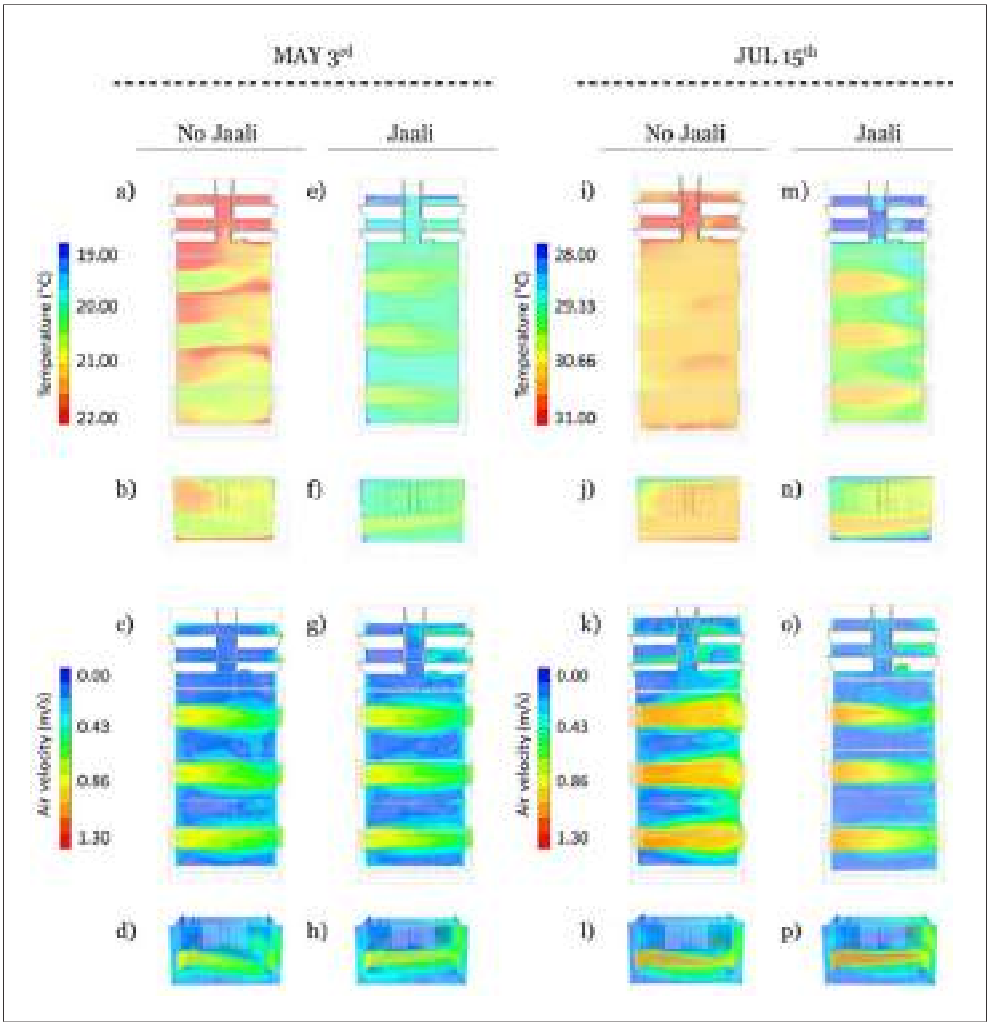

Figure 15. Air temperature and velocity distribution in the plan and East-West section for Scenario 2.

The jaalis offered slight mitigation by reducing solar gains through facade openings, resulting in lowering indoor temperatures. However, the shading effect alone was insufficient to offset the impact of high outdoor temperatures. Overall, stack ventilation was useful in May, where moderate outdoor temperatures allowed buoyancy forces to drive cooler air into the building and reduce indoor temperatures. In contrast, during peak summer, the strategy was ineffective because the outdoor air was too hot to contribute to cooling. This indicated that in climates with very high summer temperatures, stack ventilation must be combined with other strategies, like night cooling, evaporative cooling, to achieve thermal comfort.

Comparison of the Performance of Jaalis

Figures 17 and Figure 18 capture indoor hourly temperatures and relative humidity data comparing the three natural ventilation scenarios in spring and summer representative days (May 3 and July 15). The KRCC building simulation results without jaalis are presented in Figure 17, while Figure 18 shows the difference between scenarios with the use of these perforated shading screens. In Figure 18, the indoor temperatures of scenario 1, where all windows are closed, remain fairly constant without fluctuating hourly during both spring and summer representative days. On the other hand, there is an increase starting at 7am for other scenarios parallel to outdoor temperatures on both days. 4pm is the highest point for scenarios 2 and 3 indoor temperatures.

Similar to the indoor temperature graph, relative humidity trends are different for Scenario 1. Indoor relative humidity levels are constant and the lowest when windows are closed; however, in Scenarios 2 and 3, relative humidity levels change, corresponding to the increase and decrease in outdoor relative humidity during both representative days. The outdoor relative humidity level has a minimum value of 30% and reached a maximum of 97% on a spring representative day. Between 11pm and 1pm, outdoor rela-

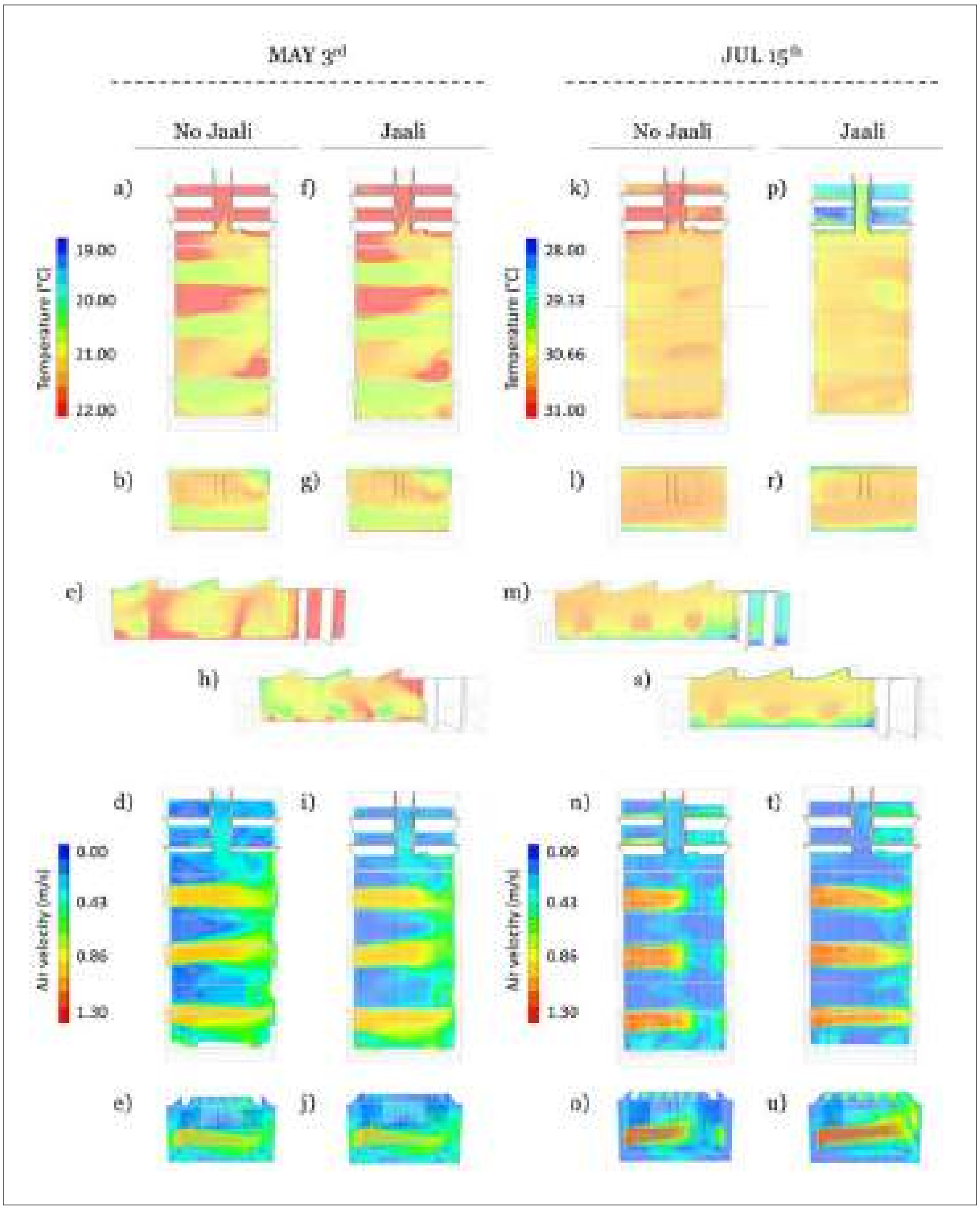

Figure 16. Air temperature and velocity distribution in plan and East-West section for Scenario 3.

tive humidity levels are higher than 80%. On July 15, the minimum value slightly drops to 27% while the maximum value is 82% at 5am.

Both Figures 17 and Figure 18 show that indoor temperatures fluctuate within a large range of ~10°C for all scenarios except scenario 1. All indoor temperature and relative humidity levels for scenarios 2 and 3 with or without jaalis follow the trend of outdoor temperature and humidity values. The most significant difference between the results of the models with jaalis and without jaalis is the indoor temperature values. Temperature diagrams in Figures 17 and Figure 18 depict that indoor temperatures decrease by about 2°C in the model with jaalis. As displayed in Figure 17, the highest indoor temperature is reached in the model without jaalis during Scenario 1 in summer. With the use of jaalis, this drops from 45°C to 43°C at 4 pm when the outdoor temperature on this representative summer day changes between 20.8 and 34.1°C.

Overall, the comparison demonstrates that jaalis consistently reduce indoor air temperatures by approximately 2°C, primarily by limiting direct solar gains while still permitting airflow. This effect is modest but significant when considered alongside the mechanisms of natural ventilation. In Scenario 1, where ventilation was absent, jaalis provided only partial relief, underscoring the limits of shading alone in overheated environments. In Scenarios 2 and 3, however, the combination

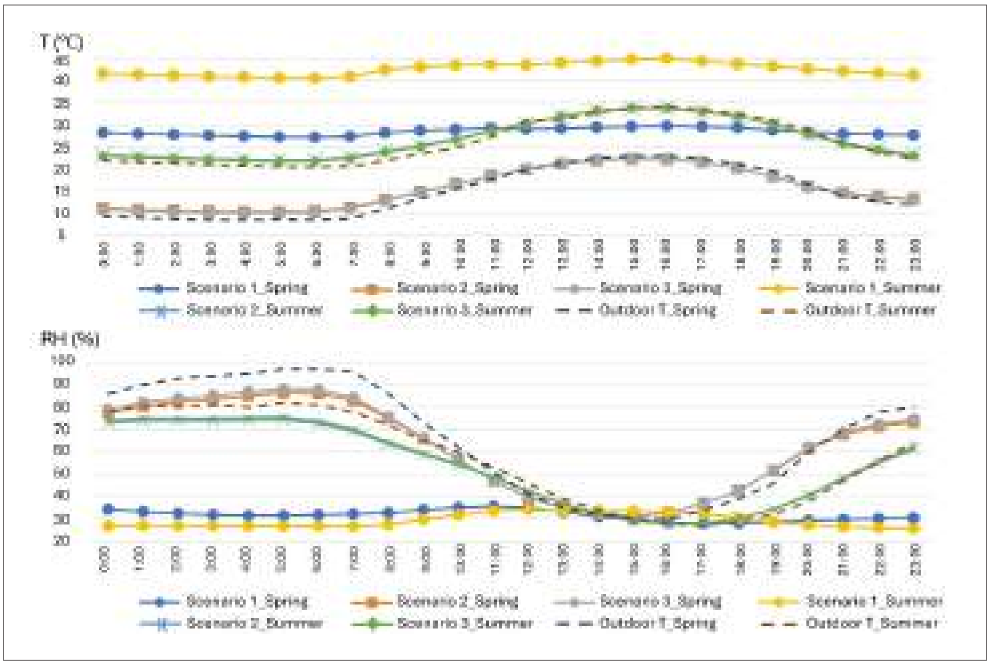

Figure 17. Comparison of the indoor temperature and relative humidity (without jaalis).

of jaalis with ventilation produced greater thermal stability. In cross ventilation, they complemented wind-driven cooling by reducing radiant loads without preventing airflow, while in stack ventilation, their benefit was more seasonal, effective only when outdoor temperatures were moderate. These findings highlight the synergistic role of jaalis since they are not a standalone solution. However, they enhance the performance of natural ventilation strategies by balancing the competing demands of shading and air movement. For hot climates like that of the KRCC building, this synergy is crucial: Cross ventilation with jaalis emerges as the most reliable passive strategy, while stack ventilation requires supplemental measures during peak summer to maintain occupant comfort.

Thermal Comfort Analysis

Thermal comfort is described as a "condition of mind that expresses satisfaction with the thermal environment (ANSI, n.b). Thermal comfort depends on environmental and per-

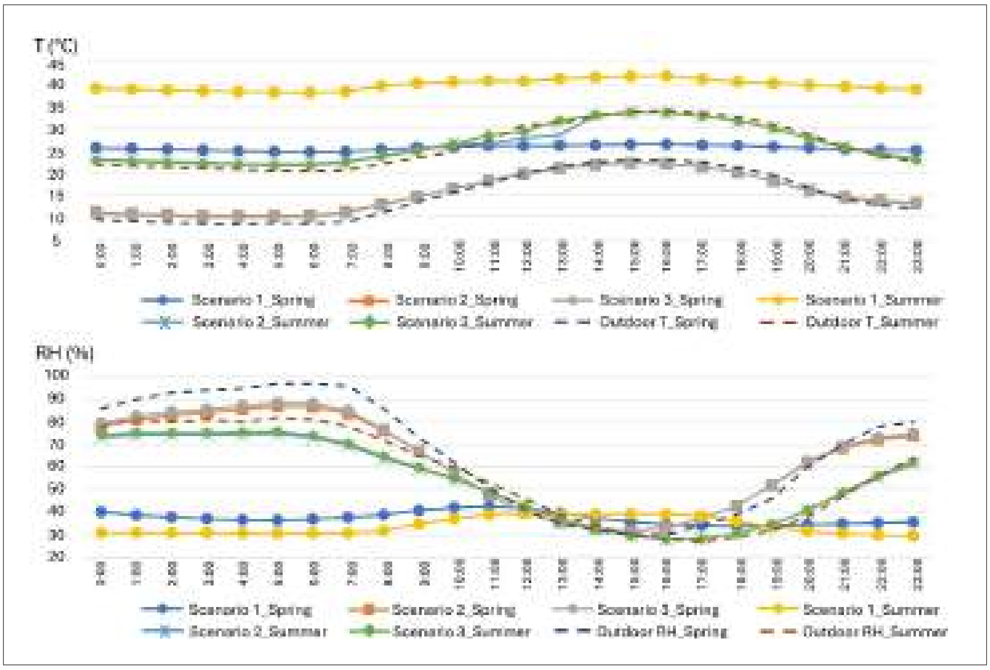

Figure 18. Comparison of the indoor temperature and relative humidity (with jaalis).

sonal variables such as temperature, relative humidity, airspeed, mean radiant temperature, clothing insulation, and metabolic rate. In this study, thermal comfort ranges on May 3 and July 15 were calculated using the Center of the Built Environment (CBE) Thermal Comfort Tool. This web-based tool was developed by UC Berkeley for thermal comfort calculations and visualizations (Tartarini et al., 2020) that complies with the ASHRAE55-2017 (ASHRAE, 2010, ISO 7730:2015, ISO 7730, 2005), EN 16798-1:2019, CEN, 2019) Standards. Multiple thermal comfort studies calculated PMV and PPD using the CBE tool (Hosseini et al., 2016; Iskandar et al., 2024; Rabeharivelo et al., 2022).

In order to evaluate if the selected natural ventilation strategies provide a thermally comfortable environment, thermal comfort zones for spring and summer representative days were generated using two variables: Air temperature (°C) and relative humidity (%). After the PMV method was selected, other parameters were entered, such as metabolic rate and clothing value. Since occupants were considered to have no local control on air velocity, it was fixed at 0.1 m/s for both representative days. Also, the metabolic rate was defined as 1.4 met. On May 3, the clothing level was 0.61 clo (trousers, long sleeve shirt) when the designated value was 0.5 clo as typical summer indoor clothing according to ASHRAE 55 (ASHRAE, 2017).

Figure 19 shows the thermal comfort zones on the selected representative days (May 3 and July 15), the hourly indoor environmental conditions of the natural ventilation scenarios, and outdoor environmental conditions. In addition, the percentage of hours within the thermal comfort zones on May 3 and July 15 is displayed in Table 4. A greater number of thermally comfortable hours was observed on the summer representative day compared to the spring representative day, where lower temperatures were recorded.

On May 3, the highest number of thermally comfortable hours indoors was seen in Scenario 1, closed windows with jaalis. Other scenarios and outdoor conditions had a similar trend, with percentages between 23% and 37 % within the thermal comfort zone. Without jaalis, cross ventilation (S2) was the second successful strategy, and no natural ventilation (S1) was the least effective approach during this spring representative day. With jaalis, stack ventilation (S3) increased comfort hours. During July 15, cross ventilation (S2) and stack ventilation (S3) provided thermal comfort. Both Scenario 2 and Scenario 3 had a higher number of thermally comfortable hours than outdoor environmental conditions. Similar to the spring representative day, the least effective approach was Scenario 1.

Overall, the thermal comfort analysis highlights that natural ventilation strategies perform differently depending on season and boundary conditions. On May 3, the presence of jaalis was decisive: While open-window strategies achieved only 23–37% of hours within the comfort zone, Scenario 1 with jaalis maintained 100% comfort, showing that a 2–3°C reduction in operative temperature was sufficient to shift conditions from slightly warm (PMV≈+1, PPD>25%) to fully acceptable (PMV≈0, PPD<10%). In contrast, on July 15, comfort could only be achieved when ventilation was introduced: Cross ventilation (S2) and stack ventilation (S3) provided 68–75% comfort hours, compared to 0% with closed windows. With jaalis, the share of comfort hours increased further, reaching 79% for cross ventilation, exceeding even outdoor comfort levels (58%). These results show that in hot-dry summer conditions, ventilation is indispensable for keeping PMV and PPD within acceptable limits, but jaalis consistently extend comfort hours by lowering radiant heat gains without impeding airflow. Taken together, the findings emphasize that while shading alone can deliver comfort

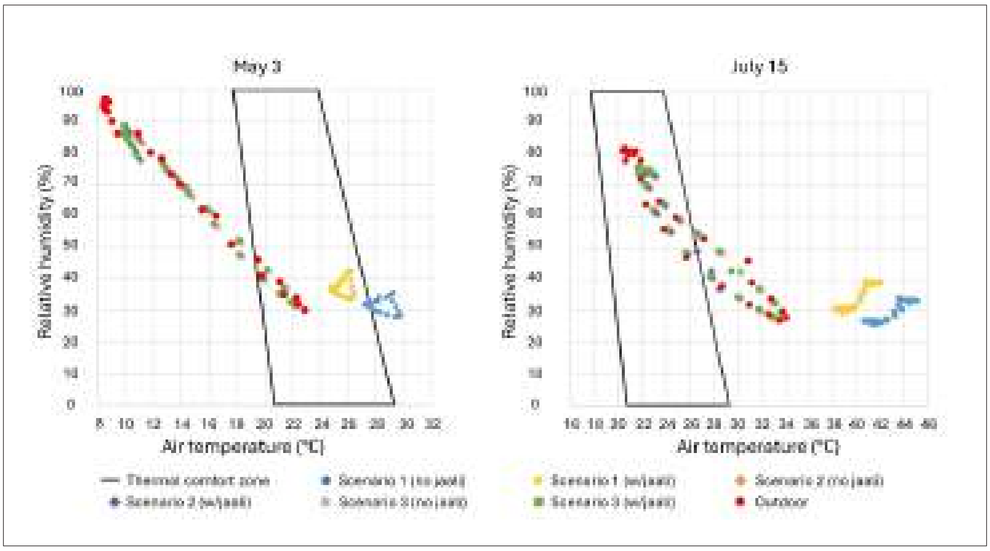

Figure 19. Thermal comfort analysis of ventilation scenarios and outdoor conditions on May 3 and July 15.

Table 4. Percentage of comfort hours in spring and summer representative days.

	Scenario 1 (no jaali)	Scenario 1 (w jaali)	Scenario 2 (no jaali)	Scenario 2 (w jaali)	Scenario 3 (no jaali)	Scenario 3 (w jaali)	Outdoor
May 3	23%	100%	37%	29%	33%	35%	33%
July 15	0%	0%	68%	79%	75%	66%	58%

during mild spring conditions, in hotter summer months, only the combination of shading and airflow can reliably maintain thermal comfort, confirming the seasonal adaptability of jaalis as an integrated passive design strategy.

CONCLUSION AND FUTURE DIRECTIONS

This study examined the effectiveness of natural ventilation strategies as passive cooling methods in a cooling-dominated, hot, and dry region. A conceptual building design for a resource and community center served as the case study. Three ventilation scenarios, no ventilation, cross ventilation, and stack ventilation, were tested both with and without jaalis installed on the main hall windows. Indoor environmental conditions were evaluated using energy simulations and Computational Fluid Dynamics (CFD) on two representative days: May 3rd (spring) and July 15th (summer).

The results showed that, on July 15th, outdoor temperatures ranged from 20.4°C to 34.1°C, while the midday indoor temperature in the baseline case (Scenario 1) reached 30.88°C. With natural ventilation, indoor temperatures slightly decreased to 29.28°C (Scenario 2) and 30.26°C (Scenario 3), and further dropped to 27.83°C and 29.48°C, respectively, when jaalis were added. On May 3rd, when outdoor temperatures were below 20°C, Scenario 1 still overheated to 29.21°C without jaalis, but dropped to 26.13°C with them. Overall, Scenario 1 was the least effective strategy, while Scenarios 2 and 3 reduced indoor temperatures by 1.5–2°C in exposed areas. Across all scenarios, jaalis consistently lowered temperatures by around 2°C, primarily by reducing solar gains without obstructing airflow.The study concludes that integrating jaalis into hot-climate buildings can enhance natural ventilation and extend the number of thermally comfortable hours. However, as the case study building has not yet been constructed, simulation results could not be validated against real-life measurements, representing a key limitation of this work.

Future research should investigate optimal porosity ratios, perforation patterns, and aperture sizes to maximize the cooling efficiency of jaalis. Additional studies could also explore (i) the interaction of jaalis with other passive cooling strategies, such as night flushing or evaporative cooling, and (ii) field validation of CFD models through post-occupancy monitoring once the building is constructed.

In conclusion, the findings demonstrate that the success of natural ventilation strategies in hot and dry climates depends on both the driving force of air movement (wind or buoyancy) and the control of solar heat gain. Scenario 1 confirmed that infiltration and shading alone cannot provide comfort in overheated spaces. Scenario 2 showed that aligning openings with prevailing winds delivers the most reliable cooling, while Scenario 3 revealed the seasonal limitations of stack-driven buoyancy when outdoor air is excessively hot. Across all scenarios, jaalis consistently enhanced performance by lowering radiant heat gains without significantly impeding airflow. Taken together, these results highlight that jaalis are most effective not as an isolated retrofit but as a synergistic element within a broader passive design strategy, where shading, ventilation, and climate-responsive operation are integrated to enhance resilience and comfort in extreme climates.

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PEER-REVIEW: Externally peer-reviewed.

CONFLICT OF INTEREST: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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REFERENCES

Aflaki, A., Mahyuddin, N., AlCheikh Mahmoud, Z., & Baharum, M. R. (2015). A review on natural ventilation applications through building façade components and ventilation openings in tropical climates. *Energy and Buildings, 101*, 153–162. https://doi.org/10.1016/j.enbuild.2015.04.033

Ai, Z. T., & Mak, C. M. (2017). CFD simulation of flow in a long street canyon under a perpendicular wind direction: Evaluation of three computational settings. *Building and Environment, 114*, 293–306. https://doi.org/10.1016/j.buildenv.2016.12.032

Albadra, D., Kuchai, N., AcevedoDelosRíos, A., RondinelOviedo, D., Coley, D., Da Silva, C. F., Rana, C., Mower, K., Dengel, A., Maskell, D., & Ball, R. J. (2020). Measurement and analysis of air quality in temporary shelters on three continents. *Building and Environment, 185*, 107259. https://doi.org/10.1016/j.buildenv.2020.107259

Ali, A. (2013). Passive cooling and vernacularism in Mughal buildings in North India: A source of inspiration for sustainable development. *Applied Sciences, 4*, 15–27.

Almhafdy, A., Ibrahim, N., Ahmad, S. S., & Yahya, J. (2015). Thermal performance analysis of courtyards in a hot humid climate using computational fluid dynamics CFD method. *Procedia – Social and Behavioral Sciences, 170*, 474–83. https://doi.org/10.1016/j.sbspro.2015.01.012

AlShamkhee, D., AlAasam, A. B., AlWaeli, A. H. A., Abusaibaa, G. Y., & Moria, H. (2022). Passive cooling techniques for ventilation: An updated review. *Renewable Energy and Environmental Sustainability, 7*, 23. https://doi.org/10.1051/rees/2022011

Amaral, A. R., Rodrigues, E., Gaspar, A. R., & Gomes, Á. (2016). A thermal performance parametric study of window type, orientation, size and shadowing effect. *Sustainable Cities and Society, 26*, 456–465. https://doi.org/10.1016/j.scs.2016.05.014

Armstrong, B. G., Chalabi, Z., Fenn, B., Hajat, S., Kovats, S., Milojevic, A., & Wilkinson, P. (2011). Association of mortality with high temperatures in a temperate climate: England and Wales. *Journal of Epidemiology and Community Health, 65*(4), 340–45. https://doi.org/10.1136/jech.2009.093161

ASHRAE. (2010). Standing Standard Project Committee 55. *ANSI/ASHRAE Standard 55*.

ASHRAE. (2017). *Standard 55: Thermal environmental conditions for human occupancy*. Retrieved Jan 15, 2025, from https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/55_2017_d_20200731.pdf

ASHRAE. (2022). *(IP Edition): Energy standard for sites and buildings except lowrise residential buildings* (ANSI Approved; IES Cosponsored). ASHRAE 90.12022.

Bay Sahin, E., Faubel, C., Iskandar, L., & MartinezMolina, A. (2025). Evaluating natural ventilation in historic buildings across US climates using CFD for future scenarios. *Journal of Architectural Engineering, 31*(4), 05025005. https://doi.org/10.1061/JAEIED.AEENG2057

Bay Şahin, E., & Elnimeiri, M. M. (2025). Thermal comfort in social housing: A case study from Türkiye's hot and dry region. *Megaron, 20*(2), 147–65. https://doi.org/10.14744/megaron.2025.55890

Bay, E. (2020). *The spatial block: Natural ventilation in hot and dry climates of Turkey* [Doctoral dissertation]. Illinois Institute of Technology.

Bay, E., MartinezMolina, A., & Dupont, W. A. (2022). Assessment of natural ventilation strategies in historical buildings in a hot and humid climate using energy and CFD simulations. *Journal of Building Engineering, 51*, 104287. https://doi.org/10.1016/j.jobe.2022.104287

Berger, M., & Worlitschek, J. (2019). The link between climate and thermal energy demand on national level: A case study on Switzerland. *Energy and Buildings, 202*, 109372. https://doi.org/10.1016/j.enbuild.2019.109372

Capeluto, I. G., & Ochoa, C. E. (2014). Simulationbased method to determine climatic energy strategies of an adaptable building retrofit façade system. *Energy, 76*, 375–84. https://doi.org/10.1016/j.energy.2014.08.028

Cavka, B. T., & Feruz, A. (2022). The impact of passive solar shading elements in traditional residential buildings of Aegean region. *Light & Engineering, 2022*, 97–105. https://doi.org/10.33383/2022020

CEN. (2019). *Energy performance of buildings – Ventilation for buildings*. EN 167981.

Chkeir, A., Bouzidi, Y., Akili, Z. E., Charafeddine, M., & Kashmar, Z. (2024). Assessment of thermal comfort in the traditional and contemporary houses in Byblos: A comparative study. *Energy and Built Environment, 5*(6), 933–45. https://doi.org/10.1016/j.enbenv.2023.07.006

Cook, M. J., Ji, Y., & Hunt, G. R. (2003). CFD modelling of natural ventilation: Combined wind and buoyancy forces. *International Journal of Ventilation, 1*(3), 169–179. https://doi.org/10.1080/14733315.2003.11683632

Demirhan, M. (n.d.). Over 133,000 houses built by TOKI not damaged in Türkiye quakes. TRT World. Retrieved May 23, 2025, from https://www.trtworld.com/turkey/over133000housesbuiltbytokinotdamagedint%C3%BCrkiyequakes65365

Dev, G., Saifudeen, A., & Sathish, A. (2021). Facade control systems for optimal daylighting: A case of Kerala. *IOP Conference Series: Earth and Environmental Science, 850*(1), 012014. https://doi.org/10.1088/17551315/850/1/012014

Du, H., Huang, P., & Jones, P. (2019). Modular facade retrofit with renewable energy technologies: The definition and current status in Europe. *Energy and Buildings, 205*, 109543. https://doi.org/10.1016/j.enbuild.2019.109543

El Semary, Y. M., Attalla, H., & Gawad, I. (2017). Modern mashrabiyas with hightech daylight responsive systems. *The Academic Research Community Publication, 1*(1), 11. https://doi.org/10.21625/archive.v1i1.113

Elhassan, Z. A. (2023). Energy consumption performance using natural ventilation in dwelling design and CFD simulation in a hot dry climate: A case study in Sudan. *Frontiers in Built Environment, 9,* 1145747. https://doi.org/10.3389/fbuil.2023.1145747

Elshaw, A., Hassan, N. M. S., & Khan, M. M. K. (2018). Computational fluid dynamic modelling and optimisation of wastewater treatment plant bioreactor mixer. *Energies, 11*(12), 3530. https://doi.org/10.3390/en11123530

Elzeyadi, I. M. K., & Batool, A. (2017, August 7). Veiled facades: Impacts of patternedmass shades on building energy savings, daylighting autonomy, and glare management in three different climate zones. *Building Simulation Conference Proceedings*. San Francisco, USA. https://doi.org/10.26868/25222708.2017.772

Elzeyadi, I., & Batool, A. (2018). Learning from the vernacular: The impacts of massive perforated screen shades on building energy savings and thermal comfort in two different hot climate zones. *ASHRAE Winter Conference Proceedings*. Chicago, USA.

Fathy, H. (2000). *Architecture for the poor: An experiment in rural Egypt*. University of Chicago Press.

Fumo, N. (2014). A review on the basics of building energy estimation. *Renewable and Sustainable Energy Reviews, 31*, 53–60. https://doi.org/10.1016/j.rser.2013.11.040

Geetha, N., & Velraj, R. (2012). Passive cooling methods for energy efficient buildings with and without thermal energy storage—A review. *Energy Education Science and Technology Part A: Energy Science and Research*, *29*, 913–946

Ghaddar, N., Kishore, R. A., Menberg, K., Ndukwu, M. C., Hou, H., Islam, R., Sahin, E. B., Sett, S., & Mandal, J. (2024). Sustainable cooling solutions. *One Earth, 7*(8), 1315–1319. https://doi.org/10.1016/j.oneear.2024.07.018

Hanam, B., Finch, G., Hepting, C., & Eng, P. (n.d.). Meter calibrated energy simulation of high rise residential buildings: Lessons learned. Conference: 13th Canadian Conference on Building Science and Technology. Winnipeg, Mantioba.

He, Q., Zhao, H., Shen, L., Dong, L., Cheng, Y., & Xu, K. (2019). Factors influencing residents' intention toward green retrofitting of existing residential buildings. *Sustainability, 11*(15), 4246. https://doi.org/10.3390/su11154246

Hooyberghs, H., Verbeke, S., Lauwaet, D., Costa, H., Floater, G., & De Ridder, K. (2017). Influence of climate change on summer cooling costs and heat stress in urban office buildings. *Climatic Change, 144*(4), 721–35. https://doi.org/10.1007/s1058401720581

Hosseini, S. H., Shokry, E., Ahmadian Hosseini, A. J., Ahmadi, G., & Calautit, J. K. (2016). Evaluation of airflow and thermal comfort in buildings ventilated with wind catchers: Simulation of conditions in Yazd City, Iran. *Energy for Sustainable Development, 35*, 7–24. https://doi.org/10.1016/j.esd.2016.09.005

IPCC. (2022). *Global Warming of 1.5°C: IPCC Special Report on Impacts of Global Warming of 1.5°C above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty* (1st edn). Cambridge University Press. https://doi.org/10.1017/9781009157940

Iskandar, L., Bay-Şahin, E., Martinez-Molina, A., & Toker Beeson, S. (2024). Evaluation of passive cooling through natural ventilation strategies in historic residential buildings using CFD simulations. *Energy and Buildings, 308*, 114005. https://doi.org/10.1016/j.enbuild.2024.114005

Iskandar, L., Faubel, C., Bay-Sahin, E., Martinez-Molina, A., & Toker Beeson, S. (2025). Climate Change Impact on Natural Ventilation Cooling Effectiveness Using CFD Simulations in Low Thermal Mass Historic Buildings. *International Journal of Architectural Heritage*, 1–25. https://doi.org/10.1080/15583058.2025.2471980

ISO. (2005). Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. ISO 7730:2005.

Jakeman, J. (2018, November 2). *British Museum's Islamic art finally gets its fairy-tale ending*. The Art Newspaper - International Art News and Events. https://www.theartnewspaper.com/2018/11/02/british-museums-islamic-art-finally-gets-its-fairy-tale-ending

Lan, L., Tsuzuki, K., Liu, Y. F., & Lian, Z. W. (2017). Thermal environment and sleep quality: A review. *Energy and Buildings*, 149, 101–113. https://doi.org/10.1016/j.enbuild.2017.05.043

Lau, A. K. K., Salleh, E., Lim, C. H., & Sulaiman, M. Y. (2016). Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: The case of Malaysia. *International Journal of Sustainable Built Environment*, *5*(2), 387–399. https://doi.org/10.1016/j.ijsbe.2016.04.004

Liu, C., Sharples, S., & Mohammadpourkarbasi, H. (2023). A review of building energy retrofit measures, passive design strategies and building regulation for the low carbon development of existing dwellings in the hot summer–cold winter region of China. *Energies, 16*(10), 4115. https://doi.org/10.3390/en16104115

Mofolasayo, A. (2022). A framework for the application of optimization techniques in the achievement of global emission targets in the housing sector. *Trends Journal of Sciences Research*, *1*(1), 73–103. https://doi.org/10.31586/wjcea.2022.512

Mohamed, M. A. (2018). The mastery of the Takhtabush as a paradigm traditional design element in the hot zone climate. EQA - I*nternational Journal of Environmental Quality, 28*, 1–11. https://doi.org/10.6092/issn.2281-4485/7661

Ohba, M., & Lun, I. (2010). Overview of natural cross-ventilation studies and the latest simulation design tools used in building ventilation-related research. *Advances in Building Energy Research, 4*(1), 127–166. https://doi.org/10.3763/aber.2009.0405

Palmero-Marrero, A. I., & Oliveira, A. C. (2010). Effect of louver shading devices on building energy requirements. *Applied Energy, 87*(6), 2040–2049. https://doi.org/10.1016/j.apenergy.2009.11.020

Parker, J. (2021). The Leeds urban heat island and its implications for energy use and thermal comfort. *Energy and Buildings*, *235*, 110636. https://doi.org/10.1016/j.enbuild.2020.110636

Prasad, R., Tandon, R., Verma, A., Sharma, M., & Ajmera, N. (2022). Jaali a tool of sustainable architectural practice: Understanding the feasibility and usage. *Materials Today: Proceedings, 60*, 513–525. https://doi.org/10.1016/j.matpr.2022.01.424

Rabeharivelo, R., Kavraz, M., & Aygün, C. (2022). Thermal comfort in classrooms considering a traditional wind tower in Trabzon through simulation. *Building Simulation, 15*(3), 401–418. https://doi.org/10.1007/s12273-021-0804-9

Rahif, R., Norouziasas, A., Elnagar, E., Doutreloup, S., Pourkiaei, S. M., Amaripadath, D., Romain, A.-C., Fettweis, X., & Attia, S. (2022). Impact of climate change on nearly zero-energy dwelling in temperate climate: Time-integrated discomfort, HVAC energy performance, and GHG emissions. *Building and Environment, 223*, 109397. https://doi.org/10.1016/j.buildenv.2022.109397

Rahman, T., Hossain Lipu, M. S., Alom Shovon, M. M., Alsaduni, I., Karim, T. F., & Ansari, S. (2025). Unveiling the impacts of climate change on the resilience of renewable energy and power systems: Factors, technological advancements, policies, challenges, and solutions. *Journal of Cleaner Production, 493*, 144933. https://doi.org/10.1016/j.jclepro.2025.144933

Santos, F. D., Ferreira, P. L., & Pedersen, J. S. T. (2022). The Climate Change Challenge: A Review of the Barriers and Solutions to Deliver a Paris Solution. *Climate*, *10*(5), 75. https://doi.org/10.3390/cli10050075

Sarihi, S., Mehdizadeh Saradj, F., & Faizi, M. (2021). A Critical Review of Façade Retrofit Measures for Minimizing Heating and Cooling Demand in Existing Buildings. *Sustainable Cities and Society, 64*, 102525. https://doi.org/10.1016/j.scs.2020.102525

Sarna, I., & Ferdyn-Grygierek, J. (2025). Natural ventilation for thermal comfort: A simulation-based comparison of manual and automated window control strategies in temperate climate housing. *Building and Environment,* 113551. https://doi.org/10.1016/j.buildenv.2025.113551

Sherif, A., El-Zafarany, A., & Arafa, R. (2012a). External perforated window Solar Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments. *Energy and Buildings, 52*, 1–10. https://doi.org/10.1016/j.enbuild.2012.05.025

Sherif, A., El-Zafarany, A., & Arafa, R. (2012b). External perforated window Solar Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments. *Energy and Buildings, 52*, 1–10. https://doi.org/10.1016/j.enbuild.2012.05.025

Simonen, K., Rodriguez, B. X., & De Wolf, C. (2017). Benchmarking the Embodied Carbon of Buildings. *Technology|Architecture + Design, 1*(2), 208–218. https://doi.org/10.1080/24751448.2017.1354623

Song, Y., Darani, K. S., Khdair, A. I., Abu-Rumman, G., & Kalbasi, R. (2021). A review on conventional passive cooling methods applicable to arid and warm climates considering economic cost and efficiency analysis in resource-based cities. *Energy Reports, 7*, 2784–2820. https://doi.org/10.1016/j.egyr.2021.04.056

Taki, A., & Kumari, H. (2023). Examining Mashrabiya's Impact on Energy Efficiency and Cultural Aspects in Saudi Arabia. *Sustainability, 15*(13), 10131. https://doi.org/10.3390/su151310131

Tartarini, F., Schiavon, S., Cheung, T., & Hoyt, T. (2020). CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX, 12*, 100563. https://doi.org/10.1016/j.softx.2020.100563

Tol, R. S. J. (2005). Adaptation and mitigation: Trade-offs in substance and methods. *Environmental Science & Policy, 8*(6), 572–578. https://doi.org/10.1016/j.envsci.2005.06.011

TUIK Kurumsal. (n.d.). [Data set].

UN report. (2020, December 16). *Building sector emissions hit record high, but low-carbon pandemic recovery can help transform sector.* https://www.unep.org/news-and-stories/press-release/building-sector-emissions-hit-record-high-low-carbon-pandemic

Wilbanks, T., Bhatt, V., Bilello, D., Bull, S., Ekmann, J., Horak, W., Huang, Y. J., Levine, M. D., Sale, M. J., Schmalzer, D., & Scott, M. J. (2008). *Effects of Climate Change on Energy Production and Use in the United States*. https://digitalcommons.unl.edu/usdoepub/12

Wimalasena, N. N., Chang-Richards, A., Wang, K. I.-K., & Dirks, K. N. (2021). Housing Risk Factors Associated with Respiratory Disease: A Systematic Review. *International Journal of Environmental Research and Public Health, 18*(6), 2815. https://doi.org/10.3390/ijerph18062815

Wu, Y., Gao, N., Niu, J., Zang, J., & Cao, Q. (2021). Numerical study on natural ventilation of the wind tower: Effects of combining with different window configurations in a low-rise house. *Building and Environment, 188,* 107450. https://doi.org/10.1016/j.buildenv.2020.107450

Yao, S., & Dang, J.-T. (2023). CFD simulation, design, and optimization for biohydrogen systems. In *Waste to*

Renewable Biohydrogen (pp. 65–91). Elsevier. https://doi.org/10.1016/B978-0-12-821675-0.00006-2

Zhai, Z. (2006). Application of Computational Fluid Dynamics in Building Design: Aspects and Trends. *Indoor and Built Environment, 15*(4), 305–313. https://doi.org/10.1177/1420326x06067336

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Article

The digital transformation of housing: A demography-sensitive scenario-based model of smart home acceptance for aging in place

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ABSTRACT

This study explores older adults' acceptance of IoT-based smart home systems using an extended Technology Acceptance Model (TAM) that incorporates trust alongside perceived ease of use (PEOU), perceived usefulness (PU), attitude toward use (ATU), and behavioral intention (BI). Data were collected from 166 older adults via visually enriched, scenario-based surveys tailored to enhance engagement and contextual comprehension. Structural Equation Modeling (SEM) and Multi-group SEM (MG-SEM) techniques were applied to examine both the general model structure and demographic moderating effects. Results reveal that trust is the most influential predictor of both PU and ATU, underscoring its central role in gerontechnological smart home acceptance decisions among older adults. PU significantly predicts ATU, which in turn strongly influences BI. While PEOU has no direct effect on ATU, it exerts a meaningful indirect effect on BI through PU and ATU. These patterns support the relevance of indirect usability pathways in technology acceptance. MG-SEM analyses highlight significant differences across demographic groups. Rural users show heightened sensitivity to ease of PEOU, whereas urban users display stronger trust-based pathways toward PU and BI. Younger elderly individuals are more influenced by ATU in forming BI, while older users associate PU and trust indicators with emotional and cognitive reassurance. Education and living environment also moderate several paths, confirming the need to consider contextual diversity in technology acceptance. This study contributes by extending TAM with trust, using scenario-based survey design, and integrating MG-SEM analyses to capture demographic and contextual variations. Findings emphasize the importance of personalized digital aging strategies and trust-based mechanisms for shaping older adults' technology acceptance.

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INTRODUCTION

Aging in place has increasingly become a core policy objective, aiming to enable older adults to maintain independent living within their current home environments (Straughan et al., 2025; Lee et al., 2024). When combined with digital health technologies and smart home solutions, this approach has substantial potential to enhance quality of life (Kutsal & Polatoglu, 2024). However, realizing this potential depends not only on technological accessibility but also on older adults' willingness to adopt such systems (Abdalrahim, 2025; Portegijs et al., 2023; Markoc & Bayram, 2025).

The Technology Acceptance Model (TAM) is one of the most widely used theoretical frameworks for explaining user behavior in the field of information systems. Its core constructs, perceived ease of use (PEOU) and perceived usefulness (PU), influence attitude toward use (ATU) and behavioral intention (BI). Yet, among older adults, this process is not shaped solely by cognitive evaluations. Emotional and relational factors, such as trust, also play a significant role in technology perceptions (Chen and Chan, 2014; Zhou et al., 2024). Therefore, the present study extends the classical TAM structure by incorporating trust as an additional determinant.

Moreover, older adults do not constitute a homogeneous group. Demographic factors such as age, gender, education, living arrangement, and settlement type can lead to meaningful differences in technology acceptance (Galkin et al., 2025). As prior research has often overlooked these demographic effects (Zhang, 2023), this study applies MG-SEM to compare structural relationships within the model across demographic subgroups.

A further contribution of this study lies in its integration of a scenario-based assessment approach. By utilizing visually supported life scenarios, participants were able to imagine and evaluate technologies they had not directly experienced, allowing the measurement of vicarious experience-based cognitive responses (Kang et al., 2020). This method offers a realistic and innovative means of assessing technology acceptance among older adults, particularly when direct experience is limited.

Taken together, the study makes three contributions: (i) extending TAM with the integration of trust, (ii) applying a scenario-based visual assessment method tailored to older adults, and (iii) testing demographic sensitivities through MG-SEM. An overview of the research design is presented in Figure 1.

In line with the analytical framework outlined above, the theoretical foundation of the study is addressed in the following section.

THEORETICAL BACKGROUND

Aging in place, gerontechnology, and IoT-based residential systems

In Turkey, approximately 80% of older adults reside in their own homes (TUIK, 2024), underscoring the growing relevance of the Aging in Place (AIP) approach. Spatial attachment, housing satisfaction, and social connections play critical roles in shaping the quality of life and psychosocial well-being of older adults (Markoc & Cinar, 2017). However, AIP should not be evaluated solely from a physical perspective. Instead, it must be understood as a multidimensional concept encompassing access to services, safety, social engagement, and technological support (Lee et al., 2024).

Gerontechnology refers to technological innovations specifically designed to support the lives of older adults. Within this scope, IoT-based systems contribute to independence and safety through functions such as remote health monitoring, fall detection, digital communication, and home automation (Rejeb et al., 2023). Yet, their effective use depends strongly on digital literacy levels and on older adults' attitudes toward technology (Zhang, 2023).

Demographic indicators in Turkey reveal significant challenges: only 12% of older adults hold a university degree, 21% are at high risk of social isolation, and partner loss is especially prevalent among women (TUIK, 2024). Healthcare utilization is also comparatively higher in this group. These findings emphasize the importance of technologies that reduce both personal and public healthcare burdens (Ahmed et al., 2025). Within the home environment, key concerns include safety, energy expenses, and support for activities of daily living. Accordingly, home automation systems, energy-efficient technologies, and mobile health services have been highlighted as vital tools for improving social sustainability (Barber, 2020; Allioui & Mourdi, 2023). A synthesis of elderly needs and corresponding IoT-based technological solutions identified in the literature is presented in Table 1.

In Turkey, only 26% of individuals aged 65 and older own a smartphone, and internet and computer usage rates remain even lower (TUIK, 2024). Notable differences also exist between rural and urban populations, while living alone significantly shapes attitudes toward technology (Markoc & Sari Haksever, 2019; 2025; Li et al., 2025).

Technology Acceptance Model (TAM) and technology adoption among older adults

The Technology Acceptance Model (TAM) (Davis, 1989) explains technology use through four primary constructs: Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitude Toward Use (ATU), and Behavioral Intention (BI). In recent years, TAM has been widely applied to examine older adults' technology adoption intentions. More recent

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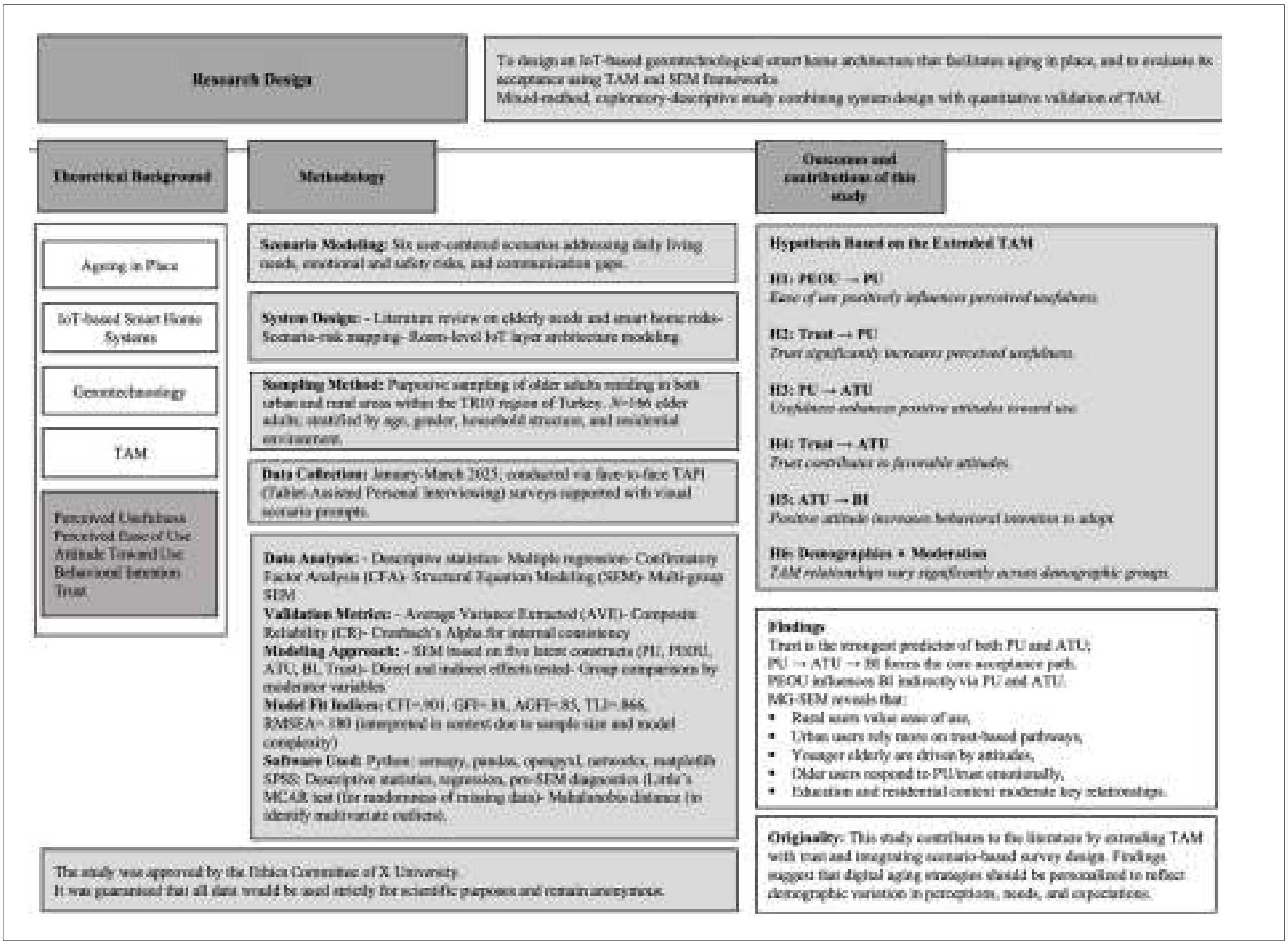


Figure 1. Research design.

Source: Designed based on the methodological framework of the study.

extensions of TAM have incorporated **trust** as a critical determinant and highlighted the moderating role of demographic factors in shaping PU and ATU (Zhou et al., 2024). Accordingly, this study adopts TAM not only as a cognitive framework but also as a socially grounded approach. Building upon structural relationships and demographic sensitivities identified in prior research, the next section details the methodology employed.

METHODOLOGY

Research Objectives and Hypothesis Development

This study aims to test the acceptance of a scenario-based, IoT-enabled smart home system developed in alignment with the principle of aging in place for older adults. The proposed framework extends the classical Technology Acceptance Model (TAM) (Davis, 1989) by integrating **trust**, which has been identified as a critical determinant in older adults' technology adoption (Zhou et al., 2024). Furthermore, the model investigates the moderating effects of demographic variables such as age, gender, and living environment on the relationships among key constructs (Galkin et al., 2025).

Previous research often treated older adults as a homogeneous group, overlooking variations in technology acceptance related to demographic characteristics. Addressing this gap, the present study proposes a model that is sensitive to demographic differences. Based on the scenario-driven system design and the extended TAM framework, the hypotheses summarized in Table 2 were developed. Hypotheses were tested through SEM and MG-SEM to evaluate the structural relationships and demographic moderating effects.

Taken together, the hypotheses presented in Table 2 establish the extended TAM framework that guides the empirical analysis. Building on this theoretical foundation, the following section introduces the study participants and describes the data collection process.

Participants

The study sample consisted of 166 older adults (*N*=166). The sample size was determined in line with the widely accept-

Table 1. Needs of elderly individuals and related technologies.

Area of Need	Proposed IoT-Based Solutions	Reference
Support for activities of daily living	Smart home assistants, automated lighting and heating systems, reminder mechanisms	Ehrenberg, 2024
Medication adherence and health monitoring	Wearable health trackers, medication dosage reminders, remote health monitoring systems	Liao et al., 2019
Indoor and outdoor security	Door/window sensors, motion detectors, smart lock systems	Sonamoni et al., 2024
Prevention of social isolation	Virtual social networks, video call-enabled digital displays, social robot applications	Welch et al., 2023
Energy efficiency and reduction of housing expenses	Smart energy meters, optimization systems for water/heat/ appliance usage	Khan et al., 2024
Accessibility and ease of use in technology	Simplified user interfaces, voice-controlled systems, large-icon mobile applications	Khamaj & Ali, 2024
Emergency assistance	Emergency alert bracelets, fall detection sensors, panic button systems	Fernández-Bermejo Ruiz et al., 2022
Access to digital healthcare services	Telehealth platforms, remote doctor consultation modules	Haleem et al., 2021

Source: Developed from thematic analysis and related literature.

Table 2. Research hypotheses guided by the extended TAM model.

Hypothesis	Statement	Rationale
H1	Perceived ease of use (PEOU) positively affects perceived usefulness (PU).	According to TAM, systems that are easier to use are more likely to be perceived as useful, particularly by older adults with limited technological familiarity. Prior studies emphasize that ease of interface design enhances functional trust and utility perception (Davis, 1989; Zhang, 2023). PEOU → PU
H2	Trust has a positive effect on perceived usefulness (PU).	Trust functions as both a cognitive and emotional facilitator in risk-prone contexts such as aging populations. When users believe that the system is reliable and secure, they tend to view it as more beneficial for health, safety, and communication needs (Zhou et al., 2024; Li et al., 2025). Trust → PU
H3	Perceived usefulness (PU) positively influences attitude toward use (ATU).	When individuals perceive a technology as valuable or life-enhancing, this fosters a favorable attitude toward use. For older adults, tangible benefits such as fall detection or medication reminders significantly strengthen acceptance (Venkatesh & Bala, 2008). PU → ATU
H4	Trust positively influences attitude toward use (ATU).	A strong sense of system trust reduces psychological resistance and fosters a positive emotional orientation toward technology. In gerontechnology contexts, trust plays a critical role in reducing anxiety and increasing openness (Chen & Chan, 2014; Zhou et al., 2024). Trust → ATU
H5	Attitude toward use (ATU) positively affects behavioral intention (BI) to adopt smart home technology.	A user's general attitude toward a system is one of the most consistent predictors of their behavioral intention. This is aligned with TAM's core pathway and has been validated across technology acceptance studies, particularly among older adults (Holden & Karsh, 2010). ATU → BI
H6	The strength of TAM relationships significantly differs across demographic groups (age, gender, living environment), indicating moderating effects.	Sociodemographic variables shape both cognitive and emotional processing of technological systems. For example, age, education, and household structure may moderate the relative importance of trust and usability in adoption intentions (Portegijs et al., 2023; Rejeb et al., 2023). Demographics X Moderation

Source: Derived from existing TAM-based models and adapted for aging-in-place contexts.

ed guideline in SEM, which recommends a minimum of 10 observations per estimated parameter to ensure robust estimation and reliable testing of path coefficients (Kline, 2023). This approach provided sufficient statistical power, thereby eliminating the need for a separate *a priori* power analysis. The socio-demographic distribution of the participants is summarized in Table 3, which presents gender, age, educational attainment, living area, and household type characteristics.

Informed by these demographic profiles, the following section describes the instruments and measures employed to evaluate the extended TAM constructs.

Table 3. Participants' socio-demographic characteristics.

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	82	49.40
	Female	84	50.60
Age	60-65	52	31.33
	66-70	42	25.30
	71-75	17	10.24
	76-80	16	9.64
	81-85	21	12.65
	85+	18	10.84
Educational Level	Primary School	35	21.08
	Secondary School	14	8.43
	High School	47	28.31
	Bachelor's Degree	52	31.33
	Master's Degree	9	5.42
	Doctorate	9	5.42
Living Area	Urban	114	68.67
	Rural	52	31.33
Household Type	Living Alone	45	27.11
	With Spouse-Partner	63	37.95
	With Spouse and Children	5	3.01
	With Caregiver-Assistant	18	10.84
	With Mother and-or Father	2	1.20
	With Children Only	9	5.42
	Extended Family	24	14.46
Total		166	100

Source: Primary survey data (2025), analyzed using SPSS v26.

Instruments and Measures

To collect data for this study, a three-part instrument was employed, consisting of visual scenario-based prompts, a TAM-based scale, and a demographic information form. First, based on a review of the literature, the needs and risk domains relevant to older adults were identified, leading to the development of eight user scenarios. These scenarios were matched with specific spaces within the smart home, associated risk factors, and corresponding IoT solution sets (Table 4).

The IoT-based solution architecture, designed in the context of residential spaces and system layers, is presented in Table 5. This approach enabled older adults to evaluate the system derived from scenario-driven cognitive responses, without requiring direct interaction or prior experience with the technology.

Technology acceptance was measured using the Technology Acceptance Model (TAM) developed by Davis (1989). The scale consisted of four core dimensions: Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitude Toward Use (ATU), and Behavioral Intention (BI). Additionally, a Trust dimension was incorporated into the model to reflect the study's focus (Chen & Chan, 2014; Zhou et al., 2024).

All items were rated using a 5-point Likert scale, and the statements were presented in a simplified language appropriate for the cognitive profiles of older adults. Demographic information, including age, gender, educational background, residential setting, and household structure, was also collected. To ensure the robustness and reliability of the dataset before conducting SEM, a series of preliminary diagnostic tests were applied. First, missing completely at random (MCAR) patterns were tested using Little's MCAR test to ensure the randomness of any missing data. Mahalanobis distance analysis was then conducted to identify multivariate outliers that could skew SEM estimations. Upon validating data quality, SEM analyses were carried out using the semopy library in Python, which enabled estimation of both direct and indirect effects. In addition to model computation, networkx and matplotlib libraries were employed to visualize the structural relationships among latent constructs and observed indicators. This integrated approach ensured both statistical rigor and visual clarity in interpreting the complex path relationships within the extended TAM framework.

FINDINGS

Initially, the 16 items within the TAM framework were presented along with their mean and standard deviation (SD) values. Across the full sample, Items 10 and 11 emerged as the most highly endorsed, whereas Items 5 and 8 received the lowest levels of agreement (Table 6).

Beyond the descriptive results, the following section explores whether these technology acceptance constructs vary according to participants' demographic characteristics.

Table 4. Scenarios and related technologies in the context of elderly individuals' needs.

Needs	Scenario Description	Risks	Related IoT-Based Solutions
Assistance with Daily Living Activities	Every morning when Ms. Ayse goes to the bathroom, the lights automatically turn on, and the home assistant provides reminders.	Disorientation, tripping, forgetfulness	Automated lighting, voice assistant, ambient temperature control, reminder systems
Medication Adherence and Health Monitoring	Mr. Can's smart bracelet collects health data, provides a visual alert at medication time, and notifies family members if a dose is missed.	Missed medication, health deterioration, delayed intervention	Wearable health trackers, smart pillbox alert systems, real-time data transmission
Indoor and Outdoor Safety	When Ms. Zeynep forgets to close the front door, the system automatically locks it. A window sensor activates in response to wind.	Unauthorized access, injury from open windows/doors	Smart locking systems, door/window sensors, automatic closure mechanisms
Mitigation of Social Isolation	The system reminds Mr. Ahmet of his scheduled video call with his grandchild and enables one-touch connection.	Loneliness, social withdrawal, cognitive decline	Integrated video communication displays, social companion robots, automated reminder tools
Energy Efficiency and Cost Reduction	Lights automatically switch off in unused rooms, and the heating system adjusts based on home occupancy.	High energy costs, inefficient resource use	Smart energy meters, environmental sensors, automated control systems
Accessibility and Ease of Use of Technology	Ms. Hakan controls devices via voice commands such as "Turn on the lights" or "Turn off the TV."	Difficulty interacting with digital devices, visual limitations	Voice-controlled interfaces, simplified user interfaces, large icons
Emergency Assistance	Mr. Murat falls in the bathroom; the sensor on his wrist detects the motion and initiates an automatic emergency call.	Fall-related injury, lack of immediate help	Fall detection sensors, emergency alert wristbands, panic buttons
Access to Digital Health Services	Ms. Yasemin conducts a remote consultation with a nurse via a smart display, with her health data preloaded.	Missed diagnosis, lack of real-time medical attention	Telehealth-enabled displays, data transmission modules, digital appointment scheduling

Source: Developed according to gerontechnology needs mapping and IoT system integration within the study.

Mean differences by demographic variables

This section investigates whether the Technology Acceptance Model (TAM) constructs differ significantly according to participants' demographic characteristics. As presented in Table 7, findings from the multiple regression analysis indicate that age is positively associated with several core constructs. Specifically, older participants reported higher levels of Perceived Ease of Use (PEOU) and more favorable Attitude Toward Use (ATU). Trust also slightly increased with age, although the magnitude was smaller compared to other variables.

Moreover, living environment showed a significant effect: participants residing in urban areas exhibited substantially higher levels of Perceived Usefulness (PU), PEOU, ATU, Behavioral Intention (BI), and Trust. Similarly, household structure emerged as an influential factor; those living alone consistently reported greater scores across PU, PEOU, ATU, BI, and Trust, suggesting that solo dwellers perceive higher relevance, usability, and reliability of the smart home system.

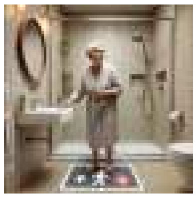
On the other hand, gender and educational level did not demonstrate statistically significant effects on any of the TAM variables. While individuals with higher education levels showed a trend toward greater ease of use, this relationship was not strong enough to reach statistical significance. These results highlight the nuanced ways demographic variables interact with technology perception, emphasizing the importance of personalized system design and targeted implementation strategies in gerontechnology contexts.

In summary, while demographic variables such as age, living environment, and household structure exert significant influences on technology acceptance, the next section employs SEM to explore the underlying causal relationships among TAM constructs.

Structural Equation Modeling (SEM) results

The five-factor technology acceptance structure (PU, PEOU, Trust, ATU, and BI) developed through Structural Equation Modeling (SEM) was tested using Confirmatory Factor Analysis (CFA). All factor loadings exceeded the threshold of .60 and were statistically significant, indicating strong convergent validity across the model constructs (Table 8).

Table 5. IoT-based system layers and components according to residential spaces.

	Entrance	Corridor	Kitchen	Living Room	Bedroom	Bathroom
Perception	Motion sensor, magnetic door sensor, facial recognition camera, RFID reader	Pressure sensor, light sensor, night motion detector	Gas detector, temperature sensor, smoke sensor, water leakage sensor	Ambient temperature-humidity sensor, motion sensor, vibration detector	In-bed pressure sensor, night motion detector, ambient light sensor, wearable health devices	Anti-slip floor sensor, water temperature sensor, fall detector, humidity sensor
Transmission	Wi-Fi, Zigbee, LoRa, RFID connectivity	BLE (Bluetooth Low Energy), Zigbee, Wi-Fi	Wi-Fi, Zigbee, NB-IoT	Wi-Fi, Z-Wave, MQTT over IP	BLE, Zigbee, Wi-Fi	Zigbee, Wi-Fi
Control/ Processing	Smart lock systems, access control scenarios	Timer-controlled lighting trigger, motion-based scenarios	Automatic stove shut-off system, voice alert module	Smart TV control unit, energy monitoring module, curtain motors	Automatic night light, emergency call systems, sleep analysis	Temperature balance control system, ventilation automation, panic button control module
Application	Mobile app notifications, video call integration	Automatic light control, remote monitoring interface	Cooking timer, energy consumption report	Voice assistant (Google, Alexa), mobile control panel	Sleep quality report, emergency notifications to relatives	Emergency call notification, water usage analytics report
						

Source: Developed within the scope of the study. Scenario illustrations were created using AI-based tools for visualization purposes only.

The overall fit of the measurement model is considered acceptable according to the following indices: CFI=0.901, GFI=0.88, AGFI=0.85, and TLI=0.866. However, the RMSEA value (0.180) is notably high. Nevertheless, the other fit indices confirm that the model demonstrates an acceptable fit within the theoretical framework. Although the RMSEA exceeds the commonly recommended upper threshold of 0.08, initially suggesting limitations in absolute model fit, this outcome can be attributed to the model's structural complexity, the inclusion of numerous paths and latent variables, and the relatively modest sample size. As Kenny et al. (2015) emphasize, RMSEA values are often inflated in small-sample, complex models; in such cases, relative fit indices such as CFI, TLI, and SRMR provide more reliable assessments. Within this context, the acceptable levels of the other indices indicate that the model is both theoretically and empirically supported. Thus, when interpreted contextually, the elevated RMSEA does not undermine the validity of the model. In addition, alternative and more parsimonious model specifications, such as versions without the Trust construct or without demographic moderation, were also explored; however, these simplified models yielded lower explanatory power and weaker fit indices, and were therefore not retained.

Examining the direct effects obtained through SEM (Table 9), Trust emerges as the strongest predictor of PU. This result robustly confirms *H2*, reinforcing the theoretical argument that trust operates as both a cognitive and emotional precursor to perceived usefulness in gerontechnological systems (Zhou et al., 2024; Li et al., 2025). While PEOU demonstrates a weak but statistically significant effect on PU, PU strongly predicts ATU, and Trust also exerts a significant influence on ATU. This finding supports *H3*, indicating that when older adults recognize clear functional benefits, such as increased independence or health monitoring, they are more likely to develop a positive attitude toward technology use. By contrast, the PEOU → ATU relationship was not statistically supported, suggesting that ease of use may influence attitude primarily indirectly through perceived usefulness. This provides empirical support for *H1*, affirming that ease of use contributes to perceived usefulness, albeit to a limited extent. The finding aligns with prior research emphasizing that intuitive system design enhances functional trust and utility perception, especially for users with limited digital proficiency.

Table 6. Descriptive statistics at the item level for technology acceptance constructs.

TAM Construct	Survey Item	Mean	SD
Perceived Usefulness (PU)	1. This system would make my home safer.	1.61	1.03
	2. This system would help monitor my health status.	1.42	0.80
	3. It would make it easier to carry out daily tasks.	1.70	1.05
	4. This system would help me live more independently at home.	1.80	1.06
Perceived Ease of Use (PEOU)	5. Learning to use this system would be easy for me.	2.62	1.21
	6. I would easily understand how to operate the devices.	2.36	1.03
	7. This system would fit well into my daily routine.	2.00	0.89
	8. Using devices through voice commands would be easy.	2.60	1.67
Attitude Toward Use (ATU)	9. Using this system would make me feel good.	1.74	1.08
	10. I would feel safer because of this system.	1.48	0.80
	11. This technology would make my life easier.	1.48	0.80
Behavioral Intention (BI)	12. I would like to use such a system in my home.	1.64	1.03
	13. I would be willing to try this system.	1.58	0.87
	14. I would use this system in my home for a long time.	1.74	1.16
Trust	15. I trust that this system would function properly.	1.52	0.93
	16. I believe it would call for help in an emergency.	2.20	0.84

Source: Based on item-level descriptive analysis of survey data collected in the current research using SPSS v26.

As expected, ATU strongly predicts BI. This confirms *H5*, underscoring that favorable attitudes, rooted in both emotional comfort and perceived benefit, are key drivers of adoption intention in smart home contexts. The standardized path coefficient exceeding 1, while uncommon, can occur due to high conceptual overlap between the ATU and BI constructs (Wolf et al., 2013; Venkatesh et al., 2003). In terms of indirect effects, PEOU influences both ATU and BI indirectly via PU. Similarly, Trust exerts a strong indirect effect on BI, mediated through both PU and ATU. This result validates *H4*, highlighting the psychological role of trust in fostering emotional safety and reducing technology-related anxiety among older individuals (Chen & Chan, 2014). Collectively, these findings underscore the pivotal role of Trust as a key determinant in technology acceptance.

The SEM diagram illustrates the standardized path coefficients (β), where each arrow indicates the direction and strength of influence between constructs. Latent variables (unobserved factors such as PU, PEOU, ATU, Trust, and BI) are represented as dark grey nodes, and each is linked to its corresponding observed indicators (survey items) via their factor loadings. This visualization displays standardized coefficients only, allowing for easier comparison of effect sizes across paths (Figure 2).

As shown in Figure 2, the structural model was tested using SEM, and the following section presents the findings of the multi-group analysis based on demographic moderators.

Multi-group SEM findings based on demographic moderators

These MG-SEM results provide robust empirical confirmation for *H6*, revealing that key TAM pathways are significantly moderated by demographic characteristics such as age, gender, education level, and residential environment. These findings underscore that older adults do not constitute a homogenous group in their technology acceptance behaviors. Instead, adoption patterns are context-sensitive and shaped by distinct cognitive, emotional, and sociocultural factors (Portegijs et al., 2023; Rejeb et al., 2023).

The MG-SEM results indicate that demographic variables, gender, age, education level, residential location, and household structure, exert significant moderating effects on several model pathways. Notably, differences based on gender and age were particularly evident for the relationships between Trust, PU, and ATU (Table 10).

Among female participants, the Trust → PU and PU → ATU pathways were stronger, whereas among males, Trust → ATU and BI → Willingness for long-term use emerged more prominently. In younger elderly participants, the ATU → BI relationship was more pronounced; for older participants, PU's emotional effect and the link between PEOU and Trust were stronger. For participants with lower educational attainment, all pathways (PEOU → PU, Trust → PU/ATU, PU → ATU) were more influential. In contexts characterized by low digital literacy, ease of use and trust played a critical role. In rural areas, the PEOU → PU and Trust → ATU rela-

Table 7. Direct effects of demographic variables on core TAM constructs.

Demographic Variable	Coefficient	p-value	Interpretation
PU - Perceived Usefulness			
Age	0.060	0.104	Slight trend (not statistically significant).
Living Environment	0.938	<0.001	Very strong effect: urban users perceive higher usefulness.
Household Structure	0.197	<0.001	Stronger usefulness perception among solo households.
PEOU- Perceived Ease of Use			
Age	0.244	<0.001	Older users perceive the system as easier to use.
Education Level	0.104	0.118	Not statistically significant; however, higher education appears to be associated with a tendency toward greater ease of use.
Living Environment	0.481	0.036	Urban residents report higher ease of use.
Household Structure	0.148	0.014	Individuals living alone or with care needs value ease of use more.
ATU- Attitude Toward Use			
Age	0.092	0.003	Older individuals show more favorable attitudes.
Living Environment	0.765	<0.001	Urban users report significantly more positive attitudes.
Household Structure	0.172	<0.001	Those living alone express more favorable attitudes.
BI - Behavioral Intention			
Age	0.114	0.003	Older users express higher intent to adopt.
Living Environment	0.811	<0.001	Urban residency strongly increases intent to adopt.
Household Structure	0.197	<0.001	Individuals living alone report greater adoption intent.
TR - Trust in the System			
Age	0.100	<0.001	Trust increases slightly with age.
Living Environment	0.598	<0.001	Rural residents report lower trust levels.
Household Structure	0.103	<0.001	Co-residence with family members is associated with lower levels of perceived trust in the system.

Source: Calculated from primary data collected in the study using regression analysis in SPSS v26.

tionships were dominant, whereas in urban areas, the PU → ATU path was stronger. These findings indicate that ease of use and trust are more salient in rural contexts, while perceived usefulness is a more decisive factor in urban settings. No significant structural differences were found across household structures, suggesting that individual perceptions may outweigh household composition in technology adoption among older adults.

DISCUSSION

This study explored older adults' acceptance of IoT-based home technologies through an extended Technology Acceptance Model (TAM), emphasizing the pivotal role of trust in shaping both perceived usefulness (PU) and attitude toward use (ATU). Consistent with *H2*, trust was found to significantly enhance PU, aligning with prior research that identifies trust as both a cognitive and emotional enabler in risk-laden contexts such as aging populations (Zhou et al., 2024; Li et al., 2025). Similarly, in line with *H4*, trust exerted a direct and meaningful influence on ATU. As Chen and Chan (2014) emphasized, trust functions as a critical affective mechanism that mitigates psychological resistance and nurtures emotional openness to technology among older users.

While perceived ease of use (PEOU) did not demonstrate a direct effect on attitude, its indirect influence through PU confirms *H1* and supports the mediated pathway described in *H3*. This finding reinforces the argument advanced by Davis (1989) and later echoed by Zhang (2023), that ease of use is valuable primarily insofar as it enhances the perceived utility of a system. In gerontechnological contexts, where older adults often rely on intuitive design and low cognitive burden, a system's usability indirectly facilitates positive attitudes, but only when perceived as functionally beneficial.

Attitude toward use (ATU) emerged as the strongest predictor of behavioral intention (BI), offering robust support for *H5*. This aligns with TAM's foundational structure and is widely supported in smart technology acceptance re-

Table 8. Factor loadings and significant interpretations.

Factor	Survey Statement	Loading (λ)	SE	p-value	Interpretation
PU	This system would make my home safer.	1.000	-	-	Independent living and assistance with daily tasks are primary determinants of perceived usefulness.
	This system would help monitor my health status.	0.610	0.041	<0.001	
	It would make it easier to carry out daily tasks.	0.945	0.038	<0.001	
	This system would help me live more independently at home.	0.943	0.039	<0.001	
PEOU	Learning to use this system would be easy for me.	1.000	-	-	Users' cognitive competence in technology shapes their perception of ease of use.
	I would easily understand how to operate the devices.	1.027	0.029	<0.001	
	This system would fit well into my daily routine.	0.695	0.051	<0.001	
	Using devices through voice commands would be easy.	0.652	0.054	<0.001	
ATU	Using this system would make me feel good.	1.000	-	-	Attitudes are shaped by psychological safety and expectations of quality of life.
	I would feel safer because of this system.	1.083	0.043	<0.001	
	This technology would make my life easier.	1.077	0.038	<0.001	
BI	I would like to use such a system in my home.	1.000	-	-	Users consider the system to be long-term and sustainable.
	I would be willing to try this system.	0.959	0.030	<0.001	
	I would use this system in my home for a long time.	1.087	0.054	<0.001	
TR	I trust that this system would function properly.	1.000	-	-	Trust regarding emergency responses may vary between individuals.
	I believe it would call for help in an emergency.	1.014	0.101	<0.001	

Source: Derived from confirmatory factor analysis conducted on TAM-based survey data.

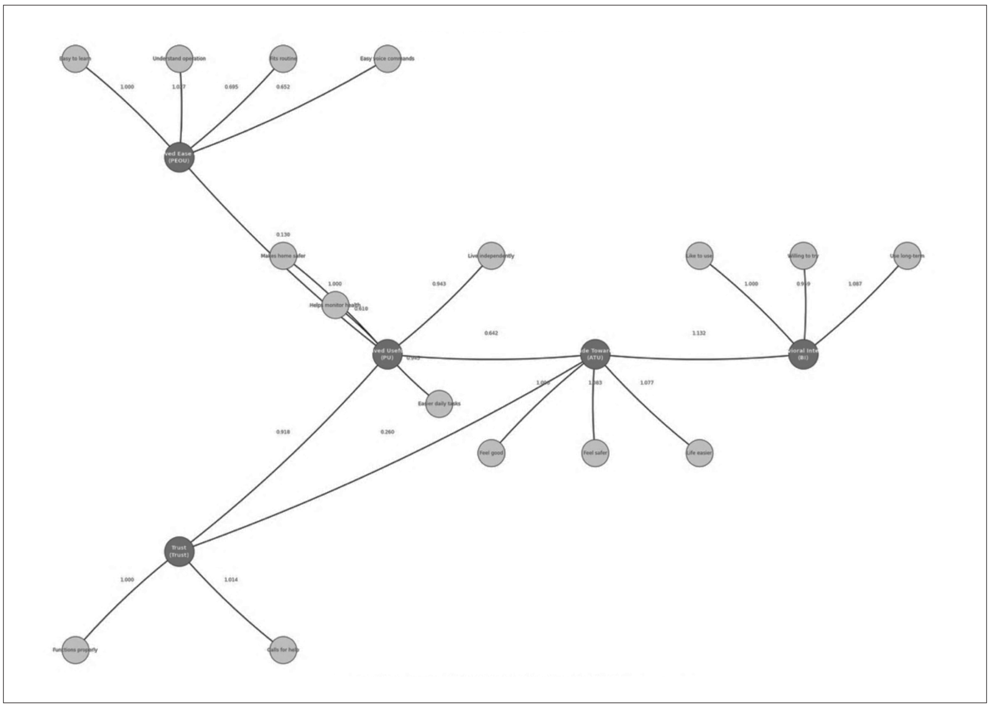


Figure 2. SEM diagram.

Source: SEM diagram constructed using Python, guided by the Technology Acceptance Model (TAM) extended with the Trust factor. The visualization was generated using networkx and matplotlib libraries within the scope of this study. Standardized path coefficients are annotated on the directional edges to represent the strength of relationships among latent constructs and observed indicators.

Table 9. Direct and indirect effects obtained within the scope of SEM.

Source	Target	Coefficient	p-value	Interpretation	Groups with Significant Differences
PEOU	PU	0.130	0.039	Significant	Family-dwelling, Rural, Younger participants
Trust	PU	0.918	<0.001	Very strong and significant	Female, Older, Higher education level, Urban
PU	ATU	0.642	<0.001	Very strong and significant	Female, Younger, Urban, All household types
PEOU	ATU	-0.002	0.943	Not significant	Weak and only significant in Older and Family-dwelling groups
Trust	ATU	0.260	<0.001	Strong and significant	Male, Older, Family-dwelling participants
ATU	BI	1.132	<0.001	Very strong and significant	Consistently significant across all demographic groups
PEOU	BI (indirect effect through PU→ATU)	≈ 0.094	-	Indirect effect	-
Trust	BI (indirect effect through PU→ATU)	≈ 0.668	-	Strong indirect effect	-

Source: Based on SEM results derived from the study data.

search involving older adults (Holden & Karsh, 2010). The emotional and psychosocial evaluation of smart home technologies, such as fall detection or medication reminders, appears to underlie the transition from favorable attitudes to concrete adoption intentions.

MG-SEM analysis revealed demographic moderation effects consistent with H6. Specifically, the strength of the PEOU → PU path was more pronounced among rural participants, potentially reflecting greater reliance on interface simplicity in less digitally saturated environments. Conversely, PU had a stronger effect on ATU in urban contexts, where technological exposure may heighten sensitivity to functional benefits. Gender-based patterns were also evident: women were more influenced by trust-mediated PU, whereas men exhibited stronger direct trust-to-attitude pathways. These findings support the notion of differentiated emotional versus functional evaluation strategies (Chen & Chan, 2014). Among lower-education participants, both trust and PEOU played amplified roles, underscoring the need for cognitive support and accessible design (Portegijs et al., 2023; Rejeb et al., 2023).

Although the scenario-based design relied on simulated rather than real-life interaction, this limitation was mitigated by adopting the vicarious experience framework (Kang et al., 2020), which emphasizes participants' ability to make informed judgments through guided visual scenarios. Nevertheless, the cross-sectional nature and geographically constrained sample may limit generalizability, suggesting the importance of future longitudinal and cross-cultural research.

Theoretically, the study makes a key contribution by integrating trust into TAM as a central construct influencing not only PU but also ATU and BI indirectly, thereby reinforcing the robustness of H2 and H4. Furthermore, the MG-SEM findings challenge the homogeneity assumption often made about older adults' technology acceptance, directly addressing critiques raised by Zhang (2023) and Chen and Chan (2014). Finally, the scenario-based approach proved effective in eliciting context-sensitive responses, offering a methodologically sound pathway for future gerontechnology research.

In addition to the current findings, the study offers several practical implications: Given older adults' reliance on trust and perceived usefulness in technology adoption, developers should prioritize simplicity, data security, and transparency in interface design. The stronger influence of ease of use among rural and lower-education groups highlights the importance of intuitive, low-cognitive-load solutions. Furthermore, the observed gender- and education-based differences suggest that awareness campaigns and training programs need to be tailored to specific demographic profiles. In this context, municipalities and healthcare providers could integrate IoT-based smart home technologies into age-friendly policies and infrastructure initiatives to support independent living among older adults.

CONCLUSION

This study provides an extended Technology Acceptance Model (TAM) analysis of IoT-based gerontechnological home systems, incorporating demographic moderators to capture the diversity of older adults' technology acceptance. Findings highlight that perceived ease of use indirectly influences attitudes through perceived usefulness, while behavioral intention is predominantly shaped by attitudes. By integrating demographic sensitivity and scenario-based evaluation, the study advances a more context-aware un-

Table 10. Multi-group SEM analysis.

Moderator	Path (Independent → Dependent)	Direction of Difference	p-value	Interpretation
Gender	Trust → PU	Stronger in females	N/A	Trust increases perceived usefulness more significantly among women.
	PU → ATU	Stronger in females	N/A	Perceived usefulness plays a more dominant role in shaping attitudes among women.
	Trust → ATU	Stronger in males	N/A	Trust has a greater influence on attitude among men.
	BI → BI.3	Stronger in males	N/A	Behavioral intention affects BI.3 more strongly in men.
Age	ATU → BI	Stronger in younger elderly	0.002	Attitude is a stronger predictor of behavioral intention in younger elderly individuals.
	PU → PU.4	Stronger in older individuals	<0.001	The emotional/cognitive impact of PU is more significant among older people.
	PEOU → PEOU.1	Stronger in older individuals	<0.001	Perceived ease of use more strongly influences age-related trust among the elderly.
	BI → BI.3	Stronger in older individuals	0.001	Behavioral intention impacts safety/comfort structures more in elderly individuals.
Education Level	PEOU → PU	Stronger in lower-educated group	<0.001	Ease of use affects PU more in individuals with lower education levels.
	Trust → PU	Stronger in lower-educated group	<0.001	The impact of trust on PU is more prominent in the lower-educated group.
	PU → ATU	Stronger in lower-educated group	0.031	Perceived usefulness has a stronger effect on attitude in less-educated individuals.
	Trust → ATU	Stronger in lower-educated group	0.001	The relationship between trust and attitude is more significant in this group.
Living Environment	PEOU → PU	Stronger in rural areas	<0.000001	Ease of use positively and strongly affects PU in rural settings.
	Trust → PU	Stronger in urban areas	<0.001	In urban settings, trust perception is more effective on PU.
	Trust ← Trust.2	Stronger in rural areas	<0.001	Trust increases more with age in rural areas.
	Trust → ATU	Stronger in rural areas	<0.01	Trust significantly influences attitude in rural contexts.
	PU → ATU	Stronger in urban areas	0.031	In urban areas, PU is a more decisive factor on attitude.
Household Structure	All paths	No significant difference	>0.05	No significant structural differences were found based on household type.

Source: Derived from MG-SEM analysis conducted on study data using Python.

derstanding of how aging populations engage with smart home technologies. In particular, living environment, education level, and digital literacy were found to significantly shape acceptance pathways. These insights call for inclusive, human-centered design strategies that emphasize simplicity, emotional reassurance, and usability for aging populations.

Limitations and Future Research

Despite its contributions, this study has several limitations. First, the cross-sectional design constrains the ability to track behavioral changes over time; longitudinal approaches are needed to capture the dynamics of acceptance. Second, reliance on self-reported data raises risks of social desirability and discrepancies between perceived and actual behaviors; future work should incorporate behavioral and usage-based measures. Third, the research was conducted within the cultural context of Turkey, which may restrict generalizability. Additionally, the fact that this study was carried out in Turkey suggests that the findings may have been influenced by the cultural context. Strong family ties, the tendency for older adults to live with family members, and widespread social responsibility norms regarding elder care may have amplified the prominent role of trust in the technology acceptance process. These cultural characteristics may have foregrounded perceptions of reliability and care support in technological systems. Future studies are therefore encouraged to investigate the generalizability of these findings across different cultural environments. Moreover, the exceptionally high standardized path coefficient between Attitude Toward Use (ATU) and Behavioral Intention (BI) (β=1.132) may indicate a partial discriminant validity limitation arising from the conceptual proximity of these constructs. Although strong theoretical justification and the CFA results support adequate convergent validity, future studies should further examine potential construct overlap using more stringent discriminant validity tests or alternative model specifications. Fourth, while the scenario-based approach supported contextual imagination, it did not allow direct interaction with technology; experimental or prototype-based designs are recommended for higher ecological validity. Fifth, the study relied on an extended TAM framework; incorporating alternative models such as UTAUT2 and constructs like facilitating conditions would offer a more comprehensive understanding. Finally, the absence of negative psychological constructs such as technophobia and privacy concerns limit the explanatory scope; their inclusion in future models could yield a more nuanced view of older adults' smart home acceptance.

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REFERENCES

Abdalrahim, A. (2025). Exploring the feasibility and acceptability of digital reminiscence therapy for people with dementia in Jordanian care homes: A qualitative study. *Working with Older People, 29*(3), 285–293. https://doi.org/10.1108/WWOP-11-2024-0078

Ahmed, S. F., Sharmin, S., Kuldeep, S. A., Lameesa, A., Bin Alam, M. S., Liu, G., & Gandomi, A. H. (2025). Transformative impacts of the internet of medical things on modern healthcare. *Results in Engineering, 25*, 103787. https://doi.org/10.1016/j.rineng.2024.103787

Allioui, H., & Mourdi, Y. (2023). Exploring the full potentials of IoT for better financial growth and stability: A comprehensive survey. *Sensors, 23*(19), 8015. https://doi.org/10.3390/s23198015

Barber, S. J. (2020). The applied implications of age-based stereotype threat for older adults. *Journal of Applied Research in Memory and Cognition, 9*(3), 274–285. https://doi.org/10.1016/j.jarmac.2020.05.002

Chen, K., & Chan, A. (2014). Gerontechnology acceptance by elderly Hong Kong Chinese: A senior technology acceptance model (STAM). *Ergonomics, 57*(5), 635–652. https://doi.org/10.1080/00140139.2014.895855

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340. https://doi.org/10.2307/249008

Ehrenberg, N. (2024). Smart home technologies: Convenience and control. In R. Rousi, C. von Koskull, & V. Roto (Eds.), *Humane Autonomous Technology*. Palgrave Macmillan. https://doi.org/10.1007/978-3-031-66528-8_8

Fernández-Bermejo Ruiz, J., Dorado Chaparro, J., & Santofimia Romero, M. J. (2022). Bedtime monitoring for fall detection and prevention in older adults. *International Journal of Environmental Research and Public Health, 19*(12), 7139. https://doi.org/10.3390/ijerph19127139

Galkin, K., Parfenova, O., & Petukhova, I. (2025). Older people during the COVID-19 pandemic in rural and urban areas: Digital technologies, medical care and adaptation. *Working with Older People, 29*(4): 348–356. https://doi.org/10.1108/WWOP-12-2024-0085

Haleem, A., Javaid, M., Singh, R. P., & Suman, R. (2021). Telemedicine for healthcare: Capabilities, features, barriers, and applications. *Sensors International, 2*, 100117. https://doi.org/10.1016/j.sintl.2021.100117

Holden, R. J., & Karsh, B. T. (2010). The technology acceptance model: Its past and its future in health care. *Journal of Biomedical Informatics, 43*(1), 159–172. https://doi.org/10.1016/j.jbi.2009.07.002

Kang, N., Ding, D., Van Riemsdijk, M. B., Morina, N., Neerincx, M. A., & Brinkman, W. P. (2020). Self-identification with a virtual experience and its moderating effect on self-efficacy and presence. *International Journal of Human-Computer Interaction, 37*(2), 181–196. https://doi.org/10.1080/10447318.2020.1812909

Kenny, D. A., Kaniskan, B., & McCoach, D. B. (2015). The performance of RMSEA in models with small degrees of freedom. *Sociological Methods & Research, 44*(3), 486–507. https://doi.org/10.1177/0049124114543236

Khamaj, A., & Ali, A. M. (2024). Examining the usability and accessibility challenges in mobile health applications for older adults. *Alexandria Engineering Journal, 102*, 179–191. https://doi.org/10.1016/j.aej.2024.06.002

Khan, Q. W., Ahmad, R., Rizwan, A., Khan, A. N., Lee, K. T., & Kim, D. H. (2024). Optimizing energy efficiency and comfort in smart homes through predictive optimization: A case study with indoor environmental parameter consideration. *Energy Reports, 11*, 5619–5637. https://doi.org/10.1016/j.egyr.2024.05.038

Kline, R. B. (2023). Structural equation modeling in neuropsychology research. In G. G. Brown, B. Crosson, K. Y. Haaland, & T. Z. King (Eds.), *APA handbook of neuropsychology: Neuroscience and neuromethods* (pp. 681–698). American Psychological Association. https://doi.org/10.1037/0000308-034

Kutsal, S., & Polatoğlu, Ç. (2024). Assessing the driving forces for future housing design. Megaron, 19(3), 344–361. https://doi.org/10.14744/megaron.2024.78477

Lee, S. W., Xu, J., Wut, T. M., Lau, Y. Y., Chan, J. H. L., Liu, T. S., Mok, L. W. Y., & Chan, J. K. Y. (2024). Aging in place in Hong Kong and its implications for sustainable development. *Sustainability, 16*(8), 3447. https://doi.org/10.3390/su16083447

Li, R., Shao, J., & Gao, D. (2025). The impact of digital literacy on the health behavior of rural older adults: Evidence from China. *BMC Public Health, 25*, 919. https://doi.org/10.1186/s12889-025-21964-5

Liao, Y., Thompson, C., Peterson, S., Mandrola, J., & Beg, M. S. (2019). The future of wearable technologies and remote monitoring in health care. *ASCO Educational Book, 39*, 115–121. https://doi.org/10.1200/EDBK_238919

Markoc, I. (2025). The digitalization tendency of young adults: differences by living environment, gender and education. *Online Information Review*, *49*(1), 136–163. https://doi.org/10.1108/OIR-01-2023-0020

Markoc, I. & Sari Haksever, T. (2019). *An Investigation of the Sense of Place Attachment According to the Age Groups*. KIE Congress Proceedings, Gaziantep, Türkiye.

Markoc, I., & Bayram, S. (2025). From experience to policy: safeguarding autonomy and privacy in digital elder care. *The Journal of Adult Protection*, *2025*, 1–15.

Markoc, I., & Cinar, C. (2017). Reading housing satisfaction parameters over housing mobility in the redevelopment process: Sarıgöl, Istanbul, Turkey. *Cogent Social Sciences*, *3*(1), 1–20. https://doi.org/10.1080/23311886.2017.1412915

Portegijs, E., Lee, C., & Zhu, X. (2023). Activity-friendly environments for active aging: The physical, social, and technology environments. *Frontiers in Public Health, 10*, 1080148. https://doi.org/10.3389/fpubh.2022.1080148

Rejeb, A., Rejeb, K., Treiblmaier, H., Appolloni, A., Alghamdi, S., Alhasawi, Y., & Iranmanesh, M. (2023). The Internet of Things (IoT) in healthcare: Taking stock and moving forward. *Internet of Things, 22*, 100721. https://doi.org/10.1016/j.iot.2023.100721

Sonamoni, J. S., Sikdar, R., Akib, A. S. M. A. S., Islam, M. S., Sourov, S., Al Ahasan, M. A., Islam, M., Habib, M. A., & Mridha, M. F. (2024). IoT-based smart remote door lock and monitoring system using an Android application. *Engineering Proceedings, 76*(1), 85. https://doi.org/10.3390/engproc2024076085

Straughan, P., Tan, Y. W., Tiew, Z., Zheng, Z., Ngu, R., & Hiah, W. T. (2025). Ageing in place, The key to receiving a superaged society. *Populations, 1*(2), 7. https://doi.org/10.3390/populations1020007

Turkish Statistical Institute (TUIK). (2024). *Elderly statistics*. Retrieved Jan 15, 2025, from https://data.tuik.gov.tr/

Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences, 39*(2), 273–315. https://doi.org/10.1111/j.1540-5915.2008.00192.x

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly, 27*(3), 425–478. https://doi.org/10.2307/30036540

Welch, V., Ghogomu, E. T., Barbeau, V. I., et al. (2023). Digital interventions to reduce social isolation and loneliness in older adults: An evidence and gap map. *Campbell Systematic Reviews, 19*(4), e1369. https://doi.org/10.1002/cl2.1369

Wolf, E. J., Harrington, K. M., Clark, S. L., & Miller, M. W. (2013). Sample size requirements for structural equation models: An evaluation of power, bias, and solution propriety. *Educational and Psychological Measurement, 76*(6), 913–934. https://doi.org/10.1177/0013164413495237

Zhang, M. (2023). Older people's attitudes towards emerging technologies: A systematic literature review. *Public Understanding of Science, 32*(8), 948–968. https://doi.org/10.1177/09636625231171677

Zhou, C., Qian, Y., & Kaner, J. (2024). A study on smart home use intention of elderly consumers based on technology acceptance models. *PLOS ONE, 19*(3), e0300574. https://doi.org/10.1371/journal.pone.0300574

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Article

DIY architecture in Türkiye: Ecological, sociopolitical and vernacular dimensions through three case studies

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ABSTRACT

This study examines DIY (Do-It-Yourself) architecture as a community-driven mode of spatial production that challenges expert-led, centralized systems of building and planning through ecological and social engagement. While the term 'DIY' gained prominence in the mid-twentieth century, its practices are deeply traceable to vernacular traditions, collective building cultures, and the fundamental human imperative to create shelter. In contemporary contexts marked by ecological crises, affordability pressures, and the erosion of local building cultures, DIY architecture has re-emerged as a significant alternative grounded in autonomy, adaptation, and user agency. Methodologically, the research employs qualitative fieldwork—including spatial documentation, 16 semi-structured interviews, archival review, and a four-dimensional analytical framework (socio-spatial motivations, material strategies, ecological adaptation, and knowledge production). Three Turkish cases—Kanlıkavak Pigeonary, Alakır Sack House, and İzmit Fishermen's Shelters—were selected for their distinct DIY typologies and traceable user-led construction histories. Findings reveal that DIY architecture cultivates ecological literacy, strengthens social bonds, and generates resilient spatial solutions through circular material use, adaptive design, and collective knowledge. Each case represents a unique mode of production: Cultural-communal making (Kanlıkavak), ecological autonomy and resistance (Alakır), and livelihood-based urban adaptation (İzmit). Together, they demonstrate forms of spatial intelligence that often lie beyond the reach of institutional delivery systems. The study reframes DIY architecture as a legitimate, future-oriented paradigm. It argues that user-driven building processes are essential for broadening participation, rethinking conservation, and advancing socially grounded and ecologically responsive architectural futures.

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INTRODUCTION

The ecological crises, deepening social inequalities, and rising urban costs of the twenty-first century have exposed the limits of conventional architectural practice. A central structural problem underlying these challenges is the professionalization of architecture: Throughout the twentieth century, design and construction increasingly moved into the hands of experts, transforming what had once been a universal human capacity—the act of building one's own shelter—into a specialized and regulated domain reserved for professional authority (Parvin, 2013). In today's rapidly changing world, where economic precarity, climate vulnerability, and resource scarcity intensify, this separation between users and the spaces they inhabit has become even more pronounced, making alternative, user-driven modes of production more relevant than ever.

Although the term "DIY" (Do-It-Yourself) gained prominence in the mid-twentieth century, its practices are deeply traceable to vernacular traditions, collective building cultures, and the fundamental human imperative to create shelter. Early forms of self-building can be traced to prehistoric shelters, Neolithic dwellings, and the informal, communal construction systems that shaped settlements across diverse geographies (Rudofsky, 1968; Smith, 2012). In its modern sense, DIY culture emerged after World War II against a backdrop of economic uncertainty and cultural transformation. Manuals such as the Whole Earth Catalog (1968–1998) empowered individuals to create, repair, and build without relying on institutional structures. The 1960s counterculture expanded DIY into the realms of self-sufficiency, communal living, and ecological awareness, accelerating its transition from a survival method into a socio-political stance.

The participation movements of the 1960s and 1970s attempted to address the growing disconnect between experts and users, but participatory design often remained limited to consultation rather than shared decision-making (Sanoff, 2000; Gardesse, 2015; Calderón, 2019). As a result, users—already marginalized by professionalization—became subject to a second exclusion through methods that lacked real influence. This double constraint encouraged a more radical approach to spatial agency.

Consequently, by the 1970s, DIY concepts began to significantly shape architectural discourse by advocating for direct user action. Fichter & Turner's (1970) Freedom to Build (1972) articulated self-building as both a personal right and a political act, arguing that housing is most effective when produced by its users. This theoretical foundation was concurrently being put into practice through pioneering architectural experiments. This wave of thinking was exemplified by a growing body of architectural work that operationalized DIY principles. Representative projects include Christopher Alexander's A Pattern Language (Alexander, et al. 1977), which provided a universal vocabulary of design patterns to empower non-professionals; Walter Segal's self-build system (1970s), which demonstrated an accessible timber-frame method for citizen builders; and Auburn University's Rural Studio (1990s–present), which redefined hands-on, socially engaged pedagogy.

This trajectory continued into the 21st century, solidifying DIY as a sustained architectural strategy. Ross (2010) documented how self-built housing in the United States became a means of asserting autonomy beyond mere economic necessity. This ethos was further advanced by models like Alejandro Aravena's incremental "half-a-house" (2000s), which embedded user-completion into formal housing policy, and open-source platforms such as WikiHouse (2010s–present), which enable digital, globally accessible self-building. These examples, among others, signal that DIY is not merely a countercultural gesture, but a global architectural strategy responding to affordability crises, ecological urgency, and demands for spatial agencies.

In the twenty-first century, DIY architecture has gained renewed momentum through ecological awareness, social justice movements, and expanding access to digital fabrication. Open-source platforms, CNC milling, community workshops, and 3D printing now enable citizens to directly participate in both design and construction, challenging professional monopolies and transforming DIY from a local craft tradition into a globally networked mode of spatial production (Dalsgaard, 2012; Garde, 2014; Fuad-Luke, 2009). Simultaneously, tactical urbanism has shown how small-scale, citizen-led spatial interventions can rapidly reshape public spaces when institutional planning proves slow or ineffective (Lydon & Garcia, 2015).

Within this broader intellectual, historical, and socio-political context, this study examines three DIY architectural cases from Turkey—Kanlıkavak Pigeonary, the Alakır Sack House, and the İzmit Fishermen's Shelters—to demonstrate how user-driven building practices emerge as responses to exclusion, ecological crises, and the need for spatial autonomy. These cases illustrate DIY architecture not as a nostalgic or peripheral phenomenon, but as a contemporary, democratic, ecological, and socially grounded production capable of addressing urgent spatial and environmental challenges.

RESEARCH METHODOLOGY

This study employs a qualitative, field-based research design framed within contemporary discourses on DIY architecture, tactical urbanism, and participatory design (Fuad-Luke, 2009; Lydon & Garcia, 2015; Sanoff, 2000). A qualitative approach is necessary to reveal aspects of tacit knowledge, embodied building practices, and non-professional construction processes that cannot be fully captured through quantitative methods.

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The investigation focuses on three cases from Türkiye (Figure 1) —Kanlıkavak Pigeonary (Eskişehir), the Alaçık & Sack House (Antalya), and the İzmit Fishermen's Shelters—selected through purposive sampling from a broader pool of approximately twenty documented DIY structures.

Analytical Framework and Case Selection

To ensure consistent analytical language across cases, the study develops a conceptual framework organized around four interconnected dimensions:

1. **Socio-spatial Motivations**: Autonomy, resistance, community formation.

Figure 1. Locations and Descriptive Profiles of the Three DIY Architecture Cases in Turkey (Photos by Author).

2. **Material and Technological Strategies**: Resource procurement, fabrication methods, circularity.
3. **Ecological Adaptation**: Environmental response, sustainability practices, climate resilience.
4. **Knowledge Production**: Tacit knowledge, skill transmission, design evolution.

The three cases were selected because they represent distinct DIY typologies: Communal production (Kanlıkavak Pigeonary), ecological self-building and resistance (Alaçık & Sack House), and autonomous habitat formation (İzmit Fishermen's Shelters). Each case offers complete and traceable construction histories, accessible field conditions, and sufficient user involvement to support robust qualitative analysis.

Data Collection and Fieldwork

Fieldwork was conducted across multiple periods using consistent methods for all cases:

- Systematic spatial observations and material inspections.
- Photographic and technical drawing documentation.
- Collection of measurements for plan-based analysis.
- Gathering of supplementary materials (construction diaries, personal archives).

Temporal distribution of fieldwork included: Kanlıkavak Pigeonary (2023-2025, field based), Sack House (2024, archival), and İzmit Fishermen's Shelters (2010, archival and field-based).

Interview Protocol and Analysis

Semi-structured interviews (16 total across all sites) explored themes of autonomy, construction processes, material reuse, ecological attitudes, and community dynamics. Participants included builders, residents, community members, and environmental activists.

A hybrid thematic analysis was undertaken using NVivo. First-cycle inductive codes were generated from field notes, interviews, and visual materials, capturing actions (building, repairing), material decisions (reuse, salvage), ecological motivations, and user-authority interactions. These descriptive codes were refined into higher-level categories through deductive engagement with literature on DIY architecture and tactical urbanism. Themes were triangulated across the four analytical dimensions and then compared across the three cases to examine how autonomy, material circularity, ecological adaptation, and knowledge transmission manifested in different contexts.

Triangulation methods included cross-referencing spatial evidence with user narratives and archival materials.

KANLIKAVAK PIGEONARY: COMMUNAL PRODUCTION AND KNOWLEDGE SHARING

The Kanlıkavak Pigeonary, built in the early 2000s by approximately 30 residents of Eskişehir's Kırmızıtoprak Neighborhood, exemplifies how DIY architecture can emerge from longstanding cultural traditions to fulfill contemporary communal needs. This case moves beyond the paradigm of individual necessity, illustrating a form of collaborative tactics (Lydon & Garcia, 2015) where spatial production becomes a medium for sustaining social bonds and intergenerational knowledge.

Socio-spatial Motivations: From Individual Need to Collective Space

The pigeonary originated when local *kuşbaz* (pigeon breeder)[1] enthusiasts found their private terraces insufficient for both husbandry and the social rituals integral to their practice. In a move that echoes the core principle of user autonomy central to DIY and participatory design (Sanoff, 2000; Fichter & Turner, 1970), the community collectively established a shared space on a donated plot of land. This transition from fragmented private domains to a unified collective venue transformed the pigeonary from a mere shelter into a dynamic social node, directly challenging the exclusion of users from spatial production in conventional planning.

Material and Technological Strategies: Organic Evolution Through User Modifications

The structure's evolution over 25 years embodies a process of incremental co-construction, where material changes are intrinsically linked to social functions. As documented in Table 1, each phase of development—from basic shelter to a space incorporating storage, socialization areas, and environmental arrangements—was driven by user modifications. This organic progression stands in stark contrast to top-down architectural delivery, showcasing a model where the built environment is continuously adapted through collective engagement.

Ecological Adaptation: Harmonious Integration with Local Conditions

The pigeonary's development demonstrates a nuanced, low-impact adaptation to its immediate environment. Figure 2 documents the initial physical transformation from a rudimentary structure to a collectively defined space, illustrating the project's responsive growth. Figure 3, the current site plan, reveals later enhancements—such as floral arrangements and textile additions—that blend micro-ecological considerations with cultural expression. This approach aligns with a key principle of sustainable vernacular architecture: The harmonization of built form with local conditions and user rhythms, rather than the imposition of standardized solutions.

Table 1. Socio-spatial evolution of the Kanlıkavak Pigeonary.

Period	Physical Features	Social Functions	Implied Knowledge Dimension
2000-2005	Basic shelter	Pigeon care	Foundational husbandry skills
2005-2010	Storage areas	Knowledge sharing	Material organization & exchange
2010-2020	Socialization spaces	Community events	Spatial negotiation for gathering
2020-Present	Environmental arrangements	Community legacy	Ecological & symbolic stewardship

Knowledge Production: Tacit Knowledge and Intergenerational Learning

Beyond its physicality, the pigeonary operates as a living repository of tacit knowledge. The evolution chronicled in Table 1 is not merely a log of physical changes but a map of accumulated, shared know-how regarding materials, construction techniques, and social organization. Knowledge is transmitted not through formal plans but through embodied practice and oral tradition, creating a resilient system of intergenerational learning. This mode of knowledge production, rooted in doing and sharing, is a cornerstone of DIY culture (Gauntlett, 2011) and highlights a form of expertise that exists outside professional domains.

The Kanlıkavak Pigeonary thus stands as a testament to how DIY architecture can foster cultural continuity and create deeply connected social spaces through collective, incremental making.

ALAKIR SACK HOUSE: ECOLOGICAL RESISTANCE AND SUSTAINABLE AUTONOMY

The Alakır Sack House, situated in Antalya's Alakır Valley, epitomizes DIY architecture as a form of materialized ecological resistance. This case moves beyond technical sustainability to demonstrate how spatial production can be a direct, activist response to environmental degradation and centralized industrial systems. It embodies what Fuad-Luke (2009) terms "design activism," where making becomes a means for socio-ecological critique and the pursuit of autonomy.

Socio-spatial Motivations: Activism as Spatial Practice

The project's genesis is inextricably linked to local activism against hydroelectric power plants, framing its construction within a broader political struggle. As Bookchin (1996) argues, superficial environmentalism often neglects the structural roots of ecological crises. The Sack House confronts this directly, serving as a built manifesto against extractive economies. The decision to self-build represents a conscious disengagement from mainstream systems, pursuing what can be defined as ecological autonomy[2]—a mode of living that prioritizes minimal consumption, direct engagement with nature, and spatial self-determination. This aligns with the ethos of tactical urbanism, where direct action creates alternatives in the face of unresponsive institutional frameworks (Lydon & Garcia, 2015).

Figure 2. User-led spatial development of the pigeonary (2023–2025) (Photos by Author).

Figure 3. Site plan with integrated built forms and landscaping (Photos by Author).

Material and Technological Strategies: Earthbag Technique and Local Sourcing

The project's materiality is central to its identity. Employing Nader Khalili's earthbag technique, the project synthesizes vernacular earth-building traditions with contemporary seismic safety principles, resulting in a low-cost, highly insulated, and environmentally responsive construction system (Kamal & Rahman, 2018). Though labor-intensive, it remains a sustainable and accessible DIY solution (Layline, 2011). The entire construction unfolded as an iterative prototyping process in which early phases—tent life, the Alaçık, and the Yuva prototype—functioned as live laboratories for refining techniques, soil mixtures, and climatic adaptations.

Figure 4 visually chronicles this phased development of the Yuva prototype, offering concrete evidence of the embodied learning and incremental skill acquisition that underpin DIY practices (Gauntlett, 2011). Figure 5, in turn, illustrates the transition from experimentation to a consolidated architectural form of Sack House, presenting user-drawn plans alongside the completed structure. Together, these visual documents demonstrate how technical knowledge emerged through hands-on trial rather than formalized expertise.

Additionally, the rigorous local sourcing of materials within a 50 km radius—and the exceptionally high reuse rate of 70%—underscores a firm commitment to circularity and a reduced ecological footprint.

Figure 4. Sequential construction phases of the earthbag 'Yuva' prototype (Erkutlu, 2012).

Figure 5. User-generated plans and completed views of the sack house (Erkutlu, 2018).

Ecological Adaptation: A Systemic, Off-Grid Ethos

The Sack House implements a fully integrated, off-grid ecological strategy, moving beyond the building envelope to holistically manage water, energy, and food systems (Table 2).

The project's quantitative performance metrics (Table 3) crystallize a systemic DIY ethos, where ecological autonomy is achieved through a deliberate, low-intensity rhythm that fundamentally redefines the tempo and resource logic of conventional construction.

Knowledge Production: Open-Source Learning and Skill Transmission

Knowledge production here was fundamentally experiential and open-source. The phased construction process (Figure 4) itself was the primary educational tool, facilitating the transmission of tacit knowledge through direct material engagement. This hands-on learning was coupled with a conscious ethos of "anti-capitalist architecture," where techniques and experiences were shared publicly, creating a model of open-source learning that empowers others.

This reinforces Gauntlett's (2011) idea of 'making is connecting,' framing the Alakır as a learning hub within a broader network of ecological resistance.

The Sack House ultimately embodies a form of DIY architecture where ecological principles, material practice, and political resistance converge to create a prototype for sustainable autonomy.

IZMIT FISHERMEN'S SHELTERS: INFORMAL URBANISM AND COMMUNITY RESILIENCE

The İzmit Fishermen's Shelters (1995–2011) represent a seminal case of informal urbanism and community-driven spatial production along Turkey's urban coastline. This self-built settlement of nearly one hundred units exemplifies how DIY architecture emerges as a tactical response to

Table 2. Integrated ecological strategy of the sack house.

Category	Application	Contribution to Autonomy & Sustainability
Preceding Experience	Tent life; Alaçık/Yuva prototypes	Served as live laboratories for iterative learning and skill refinement.
Water Management	Natural spring; rainwater harvesting	Achieved full water independence from municipal infrastructure.
Energy Systems	Solar panels; candles/gas lamps	90% reduction in lighting energy; off-grid power generation.
Food Production	Vegetable garden; livestock	Applied permaculture principles for partial food self-sufficiency.
Material Sourcing	Local stone, clay, sand; 70% reused materials	Radically reduced embodied energy and supported circular economy.
Construction Techniques	Manual labor; earthbag; green roof	Eliminated need for machinery; enhanced insulation and biodiversity.
Bioclimatic Design	23° south orientation; natural ventilation	Achieved thermal comfort without mechanical heating/cooling systems.

Table 3. Quantitative performance indicators of the sack house.

Parameter	Value	Implication
Construction Time	526 days	Embodied a slow, non-exploitative building rhythm.
Daily Workload	5 hours	Aligned construction with human and ecological cycles.
Enclosed Area	65 m^2	Embraced a minimalist spatial footprint.
Energy Consumption	0.8 kWh/day	Consumed ~5% of the energy of a conventional house.
Rainwater Harvesting	12 m^3/year	Demonstrated efficient use of on-site water resources.

the inadequacies of formal planning in providing for livelihood-based communities (Lydon & Garcia, 2015).

As shown in Figure 6, the settlement's spatial configuration becomes legible through the combination of satellite imagery and ground-level perspectives. The satellite view reveals the overall coastal layout—its crescent-shaped shoreline, branching walkways, and the linear distribution of over-water units—indicating a morphology that emerged through incremental, user-led extensions. The West and East views further illustrate how these structures were adapted to fluctuating water levels, material scarcity, and everyday fishing practices. Taken together, these multi-scalar observations exemplify what Fuad-Luke (2009) describes as "everyday design activism," where numerous small, improvised interventions accumulate over time into a resilient and collectively produced spatial system.

Its eventual demolition in 2011 starkly illustrates the tensions between such bottom-up, socially embedded habitats and top-down urban governance, raising critical questions about whose spatial practices are valued in the city.

Socio-Spatial Motivations: Autonomy, Informality, and Communal Practice

The shelters embodied "livelihood urbanism" - where spatial production directly serves economic survival and communal work patterns. Unlike the cultural focus of Kanlıkavak or ideological stance of Alakır, this case represents urban informality driven by economic necessity. This was not informal housing, but informal workplace urbanism, where spatial organization was dictated by the rhythms of fishing life rather than abstract planning regulations.

The settlement's configuration by over fifty fishermen through shared labor embodied a potent form of user autonomy, resonating with Fichter & Turner (1970) argument that users are the most effective producers of their own functional spaces.

The 2011 demolition thus represented not just the removal of structures, but the erasure of a community-defined spatial logic, also underscores the fundamental conflict between such community-built environments and formal urban governance systems.

Material and Technological Strategies: Improvisation and Adaptive Reuse

The material and structural diversity of the İzmit Fishermen's Shelters emerged from practical constraints, resource availability, and incremental user-led modification.

As illustrated in Figure 7, the façades display extensive elevational variation shaped by each builder's skills, material access, and aesthetic decisions. These user-produced elevations—ranging from patchwork claddings to improvised

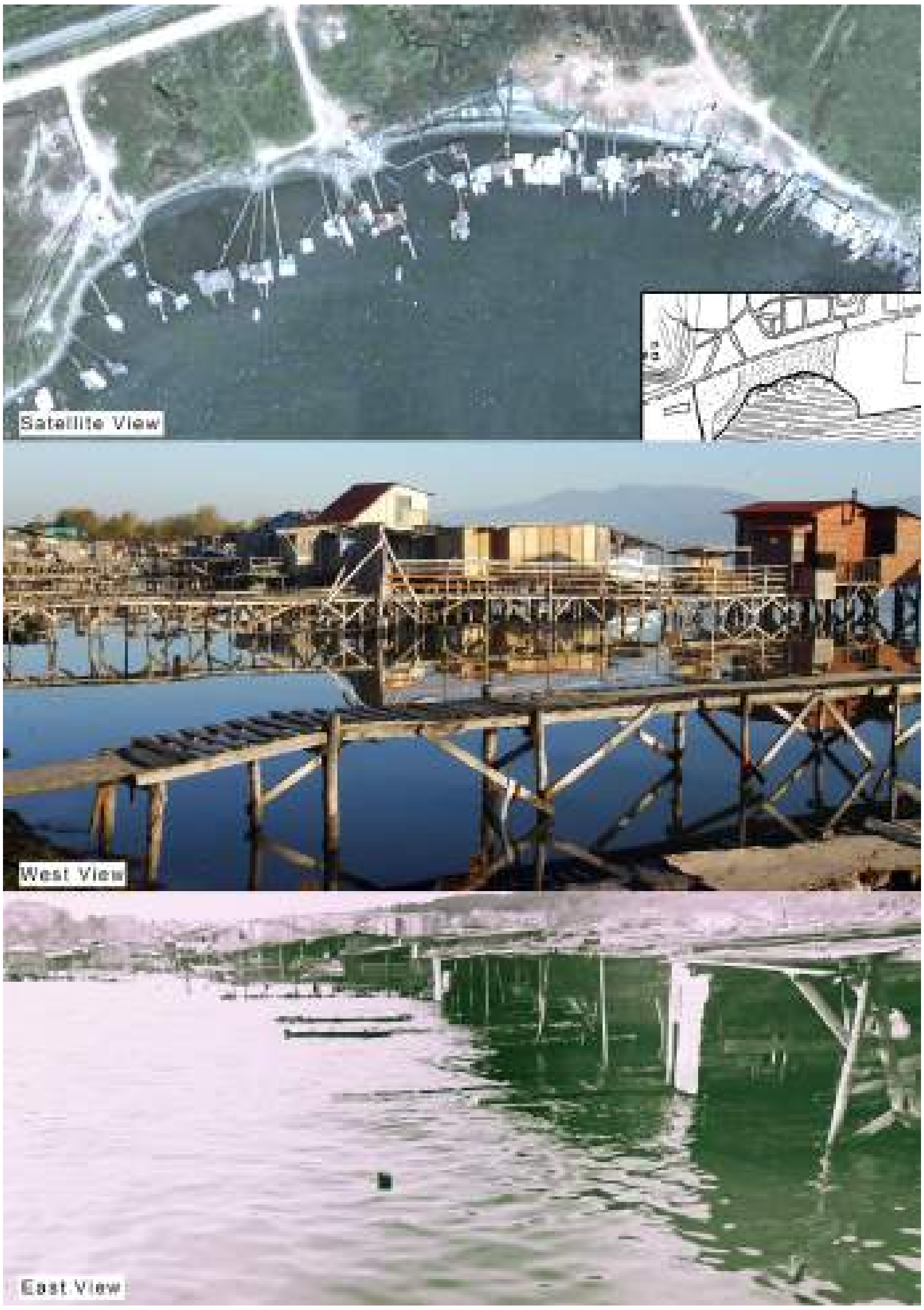

Figure 6. Coastal spatial pattern of the İzmit shelters: Satellite and ground-level views (Photos by Author; Doğukanlı, 2006a).

structural frames—make visible the intuitive, iterative nature of construction in the settlement. This heterogeneity aligns with Birsel's (2004) concept of "frog architecture"[3].

Crucially, this lightweight, flexible, and non-rigid construction logic proved exceptionally resilient to seismic forces. While the formal urban fabric of İzmit suffered catastrophic damage in the 1999 earthquake, the fishermen's shelters survived with minimal harm.

Extensions such as terraces, verandas, bridges, and multi-room layouts were incorporated over time as needs evolved, creating a dynamic and flexible spatial language. Crucially, the material logic of the shelters was shaped by extensive practices of reuse and salvage. In Figure 8, the façades were constructed using tarpaulins, billboards, scrap chipboard panels, reclaimed doors, and various other salvaged materials, while the piers and walkways were

Figure 7. Elevational variations of the İzmit fishermen's shelters (Doğukanlı, 2006a).

assembled from driftwood, discarded tires, and sea-borne debris.

The coastal environment thus functioned simultaneously as a site of deterioration—due to humidity, decay, and erosion—and as a continuous material reservoir. This continuous cycle of adaptation perfectly illustrates Turner's concept of "housing as a verb"—a spatial process rather than a finished product.

ECOLOGICAL ADAPTATION: WATER-BASED LIVING AND FLUID SPATIALITY

The shelters developed amphibious urbanism through dynamic adaptation to aquatic conditions. Figure 9—combining the settlement's plan, interior views, and the integration of boats—highlights how water was not merely a surrounding element but a defining architectural medium, while Table 4 summarizes the multi-aspect environmental negotiation. This represents a form of socio-ecological resilience where spatial intelligence emerges from lived experience rather than professional expertise, creating what might be termed "ecological democracy" in spatial practice.

Knowledge Production: Craft Learning, Repair Culture, and Collective Memory

Knowledge production here operated through craft learning and oral transmission, creating what Gauntlett (2011)

Figure 8. Recycled material practices in the İzmit shelters (Doğukanlı, 2006a; Photos by Author).

might call “making as connecting” in an urban context. The settlement functioned as a live construction laboratory where skills circulated through collective practice rather than formal training. As Doğukanlı (2006b) notes, spatial boundaries, ownership patterns, and building decisions were negotiated socially rather than bureaucratically, producing an environment governed through shared memory and mutual agreement.

This tacit knowledge system, while creating resilient communities, remained politically vulnerable due to its informality - a crucial lesson for understanding the limitations of DIY urbanism within contemporary governance frameworks.

The İzmit Fishermen’s Shelters demonstrate the capacity of informal, user-driven urbanism to generate resilient, adaptable, and socially cohesive habitats in direct response to economic and environmental conditions.

Table 4. Socio-ecological dynamics of water-based living.

Aspect	Impact Area	Manifestation in DIY Architecture
Physical	Structural Configuration	Lightweight, elevated, or floating foundations minimizing ecological impact
Social	Interaction Forms	Shared platforms and decks fostering cooperative community networks
Cultural	Everyday Practices & Traditions	Spatial layout directly facilitating fishing routines and boat-based social life
Temporal	Seasonal Adaptation	Dynamic spatial use: Open decks in summer, enclosed interiors in winter

Figure 9. Spatial and boat-integrated living in İzmit shelters (Doğukanlı, 2006a).

DISCUSSION

The three case studies examined in this research, analyzed through a consistent four-dimensional framework, collectively demonstrate how DIY architecture operates as a robust, user-driven alternative to professionalized building cultures. Rather than representing isolated or marginal practices, these cases reveal a coherent and evolving set of motivations, material strategies, and knowledge systems grounded in direct spatial agency. The comparative analysis presented in Table 5 serves as a conceptual map, illustrating the spectrum of DIY practices in Turkey—from cultural-communal production (Kanlıkavak) to ecological-activist resistance (Alakır), and socio-economic informality (İzmit).

A Spectrum of DIY Typologies: Unifying Principles and Distinct Rationales

A cross-case analysis using the four-dimensional framework, as summarized in Table 5, reveals that beneath their apparent differences lie core unifying principles. Chief among these is a process-oriented design logic where space evolves through continuous adaptation and collective decision-making, rather than being delivered as a finished product. This iterative process cultivates unique forms of resilience—social, spatial, and ecological—unattainable through top-down, standardized construction. Furthermore, across the spectrum from cultural preservation to activist resistance and economic informality, the material strategies consistently demonstrate a vernacular intelligence that prioritizes reuse, local sourcing, and low-impact techniques.

While united by these foundational approaches, each case contributes a distinct design rationale to the DIY spectrum, clarifying their unique positions within it.

The Kanlıkavak Pigeonary showcases how DIY is instrumental in sustaining cultural memory and strengthening intergenerational bonds through tacit knowledge. In stark contrast, the Alakır Sack House exemplifies a paradigm of ecological autonomy, where the very act of building becomes a form of activism and a means of physical disengagement from unsustainable systems. Finally, the İzmit Fishermen's Shelters reveal the power of improvisation and bricolage in generating adaptive urban infrastructure that responds directly to livelihood needs and economic precarity.

Theoretical Dialogue: Extending DIY and Participatory Frameworks

The findings both confirm and complicate existing theoretical frameworks by revealing that DIY architecture is driven by a complex interplay of profound motivations that yield multi-dimensional impacts. Thematic analysis demonstrates that user actions are spurred by deep-seated psychological, ecological, and socio-cultural drivers that far exceed mere functional necessity.

Table 5. Four-dimensional comparative analysis of DIY Cases in Türkiye.

Analytical Dimension	Kanlıkavak Pigeonary	Alakır Sack House	İzmit Fishermen's Shelters
Socio-Spatial Motivations	Cultural Communion: Strengthening social bonds around the tradition of pigeon breeding. Space transforms a hobby into a collective social node.	Ecological Resistance: Activism against hydroelectric power plants. Space is a tangible manifesto for the pursuit of sustainable autonomy.	Livelihood Urbanism: The practical needs of the fishing profession. Space is a habitat for economic survival and cooperative living.
Material & Technological Strategies	Incremental Co-construction: Organic evolution over 25 years through user modifications. Social functions directly inform physical form.	Iterative Prototyping & Local Sourcing: Earthbag (Superadobe) technique. A circular material economy with 70% reuse rate within a 50 km radius.	Radical Bricolage & Urban Mining: Wood, tarps, billboards, scrap doors gathered from the coast. An improvisational and contextual material language.
Ecological Adaptation	Low-Impact Harmonization: Micro-ecological arrangements (flowers, textiles). Harmonization of the built environment with user rhythms and local conditions.	Systemic Off-Grid Autonomy: Integrated water, energy, and food systems (Table 2). Radical reduction of ecological footprint.	Amphibious Resilience: Dynamic adaptation to water. Lightweight, elevated/floating foundations. Superior performance in the 1999 earthquake compared to conventional structures.
Knowledge Production	Intergenerational Tacit Knowledge: Knowledge transmitted through embodied practice and oral tradition. The space functions as a living repository of know-how.	Open-Source Experimental Learning: The construction process (Figure 4) is the primary educational tool. Techniques are shared publicly ("anti-capitalist architecture").	Craft-Based Collective Memory: Skills circulate through collective practice and a culture of repair. Spatial decisions are made through social negotiation.

As summarized in Table 6, these motivations resonate with established theories of human behavior and design, yet they manifest in the specific, grounded context of spatial production. Kanlıkavak exemplifies motivations rooted in socialization and development; Alakır embodies the pursuit of independence and environmental harmony; and İzmit reflects imperatives of necessity and collaborative practice.

Crucially, across all cases, these motivations culminate in a form of 'substantive participation' that moves beyond the consultative models critiqued by Sanoff (2000), realizing Turner's (Fichter & Turner, 1970) ideal where users are the primary authors of their spatial reality. This substantive participation, in turn, generates distinct impacts that extend theoretical discourse, particularly in terms of a 'Temporal Perception Shift' and 'Material Embodiment Experience'. The 526-day slow-building rhythm of the Sack House exemplifies a deliberate temporal decolonization (Adam, 1998), while the İzmit settlement's survival of the 1999 earthquake provides empirical evidence for "vernacular structural intelligence"—a form of resilience emerging from adaptive, lightweight construction rather than top-down engineering.

A Value System, Not Just a Technique

The conceptual worldview of DIY builders, distilled from the discourse and encapsulated in Table 7, underscores that DIY is a coherent value system, not merely a set of techniques. This framework moves beyond singular motivation or impacts to articulate the fundamental aspects that constitute the DIY ethos, highlighting its potential as a holistic alternative to conventional practice.

Implications for Architectural Conservation: Challenging Static Paradigms

The cases present a profound challenge to traditional architectural conservation, which often prioritizes material authenticity and fixed states. Instead, they advocate for a 'processual conservation' paradigm that values continuous adaptation, community knowledge transmission, and evolving spatial practices. The demolition of the İzmit shelters represents a critical failure of heritage recognition systems that cannot accommodate informal, community-built environments. This suggests the need for expanded heritage criteria that can recognize the value of social practices, repair cultures, and collective memory—the very elements that constitute the living value system outlined in Table 7.

Policy, Educational, and Future Research Directions

Policy Recommendations:

- Develop "adaptive building codes" that accommodate low-impact, user-built structures.
- Establish "community land trusts" to secure tenure for informal settlements with proven socio-ecological value.
- Create municipal "material banks" for salvaged construction materials to support circular economies.

Educational Implications:

- Integrate "hands-on building literacy" into core architectural curricula through mandatory workshops.
- Develop courses on "community facilitation" to supplement traditional expert-design training.

Table 6. Motivations and impacts of DIY architecture: A thematic synthesis.

Theme	Core Concept (Motivation)	Representative Discourse	Key Impact / Dimension	Theoretical Connection
Autonomy & Self-Determination	Process-oriented personal right and freedom	"Longing to own one's time..." (P9, 2024)	Identity Construction; Temporal Shift	Self-Determination Theory (Deci & Ryan, 2000); Autonomy Theory (Ryan, 1991)
Ecological Awareness & Harmony	Conscious human-nature relationship	"Building with natural materials helped me reconnect..." (P7, 2024)	Resource Efficiency; Energy Balance; Biodiversity	Biophilia Hypothesis (Kellert & Wilson, 1993); Ecological Design (Van der Ryn & Cowan, 1996)
Socialization & Community	Collaborative community building	"This process creates community..." (P5, 2023)	Social Capital Formation	Social Capital Theory (Putnam, 2000)
Personal Fulfillment & Actualization	Existential fulfillment through creation	"We started this journey to live authentically..." (P15, 2024)	Existential Fulfillment; Hands-on Materiality	Positive Psychology (Seligman, 2002); Logotherapy (Frankl, 1959); Craft Theory (Sennett, 2008)
Necessity & Pragmatism	Basic need fulfillment and problem-solving	"Creating space was a fundamental need" (P12, 2024)	Practical Skills & Knowledge; Minimalist Design	Experiential Learning (Kolb, 1984)

Table 7. The DIY architecture value framework.

Fundamental Aspect	Core Keywords
Spatial Agency & Autonomy	Independence, Freedom, Self-sufficiency, Construction freedom, Sense of Ownership
Ecological Integration	Sustainability, Harmony with nature, Recycling, Eco-friendliness, Natural materials
Socially Embedded Production	Social connections, Sharing, Teamwork, Social Solidarity, Community-building
Personal Empowerment & Growth	Personal satisfaction, Value of one's labor, Joy of self-production, Mental well-being, Personal development
Resourceful & Practical Intelligence	Handicraft, Artisanship, Practical intelligence, Quick problem-solving, applied knowledge, Low cost, Efficiency

- Establish "live project studios" where students collaborate directly with community builders.

Limitations and Future Research: This study is limited by its qualitative methodology and focus on the Turkish context. Future research should:

- Quantitatively assess the environmental performance of DIY structures through life-cycle analysis.
- Conduct longitudinal studies tracking social capital formation in community-built projects.
- Explore the potential of digital fabrication to scale DIY principles while maintaining localization.
- Investigate policy frameworks in other contexts that successfully integrate informal building practices.

This study positions DIY architecture not as a marginal phenomenon but as a viable, future-oriented strategy. It demonstrates the capacity of user-driven processes to generate culturally resonant, ecologically intelligent, and socially resilient habitats, offering a critical model for rethinking both architectural practice and conservation in the 21st century.

CONCLUSION

This study demonstrates that DIY architecture is not a marginal improvisational activity but a significant socio-ecological practice that reshapes how individuals and communities produce, inhabit, and sustain their environments. Through three cases from Turkey—Kanlıkavak Pigeonary, the Alakır Sack House, and the İzmit Fishermen's Shelters—the research reveals that DIY architecture constitutes a holistic mode of spatial production grounded in user agency, ecological adaptation, and collective knowledge rather than professional authority. Each case shows how bottom-up building practices can generate spatial outcomes that are socially cohesive, materially resourceful, and environmentally responsive in ways that conventional architectural systems struggle to provide.

Across the three cases, several unifying principles emerge. First, all demonstrate that spatial agency expands dramatically when users reclaim the right to build. Whether through communal making (Kanlıkavak), ecological self-sufficiency (Alakır), or livelihood-driven informality (İzmit), DIY practices cultivate autonomy, ecological sensitivity, and social solidarity. Second, all cases illustrate a process-oriented design logic in which space evolves through continuous adaptation, repair, and collective decision-making. This iterative process produces forms of resilience—social, spatial, and ecological—that cannot be replicated through top-down, standardized construction. Third, the material strategies observed across cases highlight vernacular intelligence that embraces reuse, local sourcing, and low-impact techniques, reinforcing the centrality of embodied knowledge and ecological awareness in sustainable architecture.

The thematic analysis further confirms that the motivations behind DIY architecture—ranging from self-determination and ecological awareness to craft learning and self-actualization—are not secondary but fundamental elements of the building experience. These findings align with established theoretical frameworks such as autonomy theory, biophilia, experiential learning, and social capital theory. Together, they show that DIY practices cultivate ecological literacy, strengthen communal bonds, and enhance individual well-being, offering a multidimensional alternative to consumer-driven, resource-intensive architectural models.

The implications for contemporary architectural conservation and planning are profound. Rather than treating DIY structures as temporary, informal, or expendable, conservation frameworks should recognize them as living systems of cultural memory and ecological intelligence. The demolition of the İzmit Fishermen's Shelters illustrates the vulnerability of community-built environments under current regulatory regimes and highlights the urgent need for heritage criteria that include social practices, craft cultures, and adaptive spatial traditions—not only physical monuments. Expanding conservation paradigms in this direction would align architectural heritage with contemporary debates on sustainability, participatory design, and environmental justice.

Table 8. Implementation Framework for DIY Architecture Integration.

Policy Area	Key Proposals	Implementation Steps	Responsible Actors
Legal Framework	Develop adaptive building codes	Create regulations for low-impact, user-built structures	Local governments, Parliament
	Recognize collective ownership models	Establish legal frameworks for housing cooperatives	Ministry of Justice, Municipalities
Education & Training	Integrate DIY studios into curricula	Develop hands-on building courses	Universities, Accreditation boards
	Organize community workshops	Create skill-sharing programs for vernacular techniques	NGOs, Professional chambers
Spatial Resources	Establish community workshops	Provide public spaces for collaborative building	Municipalities, Community organizations
	Create material recycling hubs	Develop networks for reclaimed building materials	Ministry of Environment, Municipalities
Community Participation	Enhance neighborhood decision-making	Implement participatory planning processes	Local governments, Civil society
	Organizing design workshops	Facilitate community visioning events	Municipalities, Universities
Cultural Heritage	Document DIY structures	Create inventories of community-built environments	Ministry of Culture, Universities
	Support living heritage practices	Conduct oral history and community memory projects	Museums, Cultural organizations

Based on these insights, the study proposes a comprehensive framework for integrating DIY architecture into architectural practice and planning policy (Table 8). This includes adaptive building codes, community-led material infrastructures, participatory planning tools, hands-on education within architectural curricula, and cultural protection mechanisms for living building traditions. Taken together, these strategies aim to transform DIY architecture from a set of isolated practices into a coherent, institutionally supported approach with relevance for contemporary and future architectural challenges.

Ultimately, this research demonstrates that DIY architecture matters today because it challenges the foundational questions of modern architectural practice: *"Who has the right to produce space? Whose knowledge counts? How can building be reconnected with ecological responsibility and social meaning?"* By foregrounding user agency, vernacular resilience, ecological alignment, and collective creativity, DIY architecture provides a powerful model for rethinking architectural production in the twenty-first century. Its capacity to sustain local memory, strengthen community identity, and reinforce ecological stewardship suggests that user-driven construction is not merely a historical remnant, but an essential component of a more just, sustainable, and meaningful built environment.

NOTES

[1]Pigeons have maintained cultural significance since the Oghuz tribes, transitioning from palace life to popular practice (Kaplan, 2007). The tradition has evolved into a social practice where knowledge exchange about care, training, and breeds occurs among enthusiasts (Korkmaz, 2022).

[2]As people increasingly feel the effects of ecological degradation, awareness of concepts like the "ecological footprint" has spurred environmental research and sustainable initiatives since the 1970s (Ciravoğlu, 2008)

[3]*"Frog architecture"* is a concept developed by Sedef Birsel based on her observations of the İzmit fishermen's shelters. Birsel (2004) describes these structures as dwellings that could be built with "a pair of long boots, a saw, a few nails, and some arm strength," shaped entirely by users' imagination and practical ingenuity, where even the walls, rooms, or terraces could be configured however one wished. The term is used metaphorically to emphasize how this spontaneous and low-cost mode of production departs from formal planning norms; Birsel characterizes these structures as a spatial formation that "grows, jumps, and multiplies like a frog," expanding incrementally through user-led additions.

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REFERENCES

Adam, B. (1998). *Timescapes of modernity: The environment and invisible hazards*. Routledge.

Alexander, C. (1979). *The timeless way of building*. Oxford University Press.

Bookchin, M. (1996). *Ekolojik bir topluma doğru [Toward an ecological society]*. Ayrıntı Yayınları.

Calderón, C. (2019). The limits of participation: A critical review of participatory planning. *Urban Planning, 4*(1), 12–25. https://doi.org/10.17645/up.v4i1.1660

Ciravoğlu, A. (2008). Sürdürülebilir mimarlık düşüncesi ne kadar sürdürülebilir? [How sustainable is the concept of sustainable architecture]. *Mimarlık Derg, 340*, 1698.

Daily, G. C. (Ed.). (1997). *Nature's services: Societal dependence on natural ecosystems*. Island Press.

Dalsgaard, P. (2012). Participatory design in large-scale public projects: Challenges and opportunities. *Design Issues, 28*(3), 34–47. https://doi.org/10.1162/DESI_a_00150

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

Doğukanlı, H. (2006a). *İzmit fishermen's shelters [Photograph]*. Personal archive.

Doğukanlı, H. (2006b). Oluşum olarak balıkçı barakaları [Fishermen's shacks as formation]. *DOXA, 1*(2), 210.

Erkutlu, B. (2012, May 15). Yuva: Doğada, maddi ve manevi maliyeti az, sağlıklı ev yapımı [Home: Healthy house construction in nature with low material and spiritual cost]. https://mithatmarul.wordpress.com/2012/05/15/baska-bir-mimari-mumkun-yuva/

Erkutlu, B. (2018). *Sack House [Photograph]*. Personal archive.

Fichter, R., & Turner, J. F. C. (1970). *Freedom to build: Dweller control of the housing process*. Macmillan.

Fuad-Luke, A. (2009). *Design activism: Beautiful strangeness for a sustainable world*. Earthscan.

Fukuyama, F. (1995). *Trust: The social virtues and the creation of prosperity*. Free Press.

Gardesse, C. (2015). Understanding public participation in urban design: A critical perspective. *International Journal of Urban and Regional Research, 39*(2), 284–302. https://doi.org/10.1111/1468-2427.12278

Garde, A. (2014). Citizen participation and design: The role of digital tools in collaborative urbanism. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability, 7*(2), 111–128. https://doi.org/10.1080/17549175.2013.865063

Kamal, R., & Rahman, M. S. (2018). A study on feasibility of Super Adobe technology—An energy-efficient building system using natural resources in Bangladesh. *IOP Conference Series: Earth and Environmental Science, 143*(1), 012043. https://doi.org/10.1088/1755-1315/143/1/012043

Kaplan, M. (2007). *Türk edebiyatı üzerinde araştırmalar 3: Tip tahlilleri [Research on Turkish literature 3: Character analyses]*. Dergâh Yayınları.

Kellert, S. R., & Wilson, E. O. (1993). *The biophilia hypothesis*. Island Press.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice-Hall.

Korkmaz, M. (2022). İstanbul folklorunda kuşçuluk [Birdkeeping in Istanbul folklore]. *Motif Akademi Halkbilimi Dergisi, 15*(40), 1372–1391. https://doi.org/10.12981/mahder.1208755

Layline, T. (2011, December). *Nader Khalili built earth buildings fit for space*. Green Prophet. https://www.greenprophet.com/2011/12/nader-khalili-earth-buildings/

Lydon, M., & Garcia, A. (2015). *Tactical urbanism: Short-term action for long-term change*. Island Press.

Özçelik, T. (2011, September). *İzmit Fishermen's Shelters*. Personal interview.

Parvin, A. (2013). Architecture (and the other 99%): Open-source architecture and the design commons. *Architectural Design, 83*(6), 90–95. https://doi.org/10.1002/ad.1564

Putnam, R. D. (2000). *Bowling alone: The collapse and revival of American community*. Simon & Schuster.

Ross, A. (2010). *Building (in) the future: Recasting labor in architecture*. Princeton Architectural Press.

Rudofsky, B. (1968). *Architecture without architects*. Doubleday.

Ryan, R. M. (1991). The nature of the self in autonomy and relatedness. In J. Strauss & G. R. Goethals (Eds.), *The self: Interdisciplinary approaches* (pp. 208–238). Springer-Verlag.

Sanoff, H. (2000). *Community participation methods in design and planning*. John Wiley & Sons.

Seligman, M. E. P. (2002). *Authentic happiness: Using the new positive psychology to realize your potential for lasting fulfillmen*t. Free Press.

Sennett, R. (2008). *The craftsman*. Yale University Press.

Smith, C. D. (2012). *Productive matters: The DIY architecture manuals of Ant Farm and Paolo Soleri [PhD dissertation]*. University of Sydney.

Van der Ryn, S., & Cowan, S. (1996). *Ecological design (10th anniversary ed.)*. Island Press.

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Article

Residential satisfaction in urban historical districts and human needs: An environmental affordance approach (Sabzevar, Iran)

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ABSTRACT

Despite their historical, cultural, and social significance, many historic urban districts struggle to meet residents' needs, thereby undermining residential satisfaction and quality of life. The historic district of Sabzevar, Iran, exemplifies this challenge, as aging residents increasingly leave due to declining satisfaction. This study investigates how deficiencies in environmental affordances — the environment's capacity to support human needs — contribute to this trend. Using a mixed-methods approach and path analysis, we identify four key dimensions of affordance: Physical-spatial (comfort, security), functional (accessibility, flexibility), perceptual-psychological (legibility, safety, place attachment), and socio-cultural (social interaction, aesthetics). Findings reveal low overall residential satisfaction, with the perceptual-psychological dimension emerging as the strongest predictor ($\beta=0.55$, $p<0.05$), likely due to its role in fostering emotional attachment and perceived safety — critical factors for aging populations in historic settings. While socio-cultural affordances remain relatively strong (preserving community identity), physical-spatial and functional dimensions are critically deficient. Based on these findings, we propose context-specific urban design interventions — including shaded rest areas, traffic calming, Lynchian legibility enhancements, and CPTED-based safety measures — to improve livability and support resident retention. This study advances the application of Maslow's hierarchy within affordance theory and offers actionable insights for human-centered revitalization of historic districts.

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INTRODUCTION

Preserving the historical, cultural, and social fabric of old urban districts is not merely an aesthetic or heritage concern — it is a critical component of equitable, human-centered urban policy. Yet, in many cities, including Sabzevar in Khorasan Razavi Province, these districts are increasingly marginalized under top-down planning paradigms that prioritize large-scale development over the lived experience of residents (Chokhachian, Santucci & Auer, 2017). The historic core of Sabzevar, despite its rich identity and communal vitality, suffers from a visibly degraded physical fabric — crumbling pavements, inadequate shading, and fragmented accessibility — conditions that directly contribute to the gradual outmigration of its elderly residents (Fayaz, et al., 2019, p. 234; Haft Shahr Aria, 2012). This displacement is not random; it is a direct consequence of declining residential satisfaction — a phenomenon deeply tied to the environment's failure to respond to residents' evolving needs (Saffari Nia, et al., 2013, p. 43; Dannenberg, et al., 2011; Fernandez-Portero, et al., 2017; Temelova & Dvorakova, 2012).

Central to this study is the concept of environmental affordance — the perceived and actual capacity of the built environment to support human action and well-being. Unlike conventional urban metrics that focus on form or function alone, affordance theory — rooted in Gibson's (1979) work — emphasizes the relationship between people and place: A shaded bench affords rest to a tired elderly resident; a familiar alley affords orientation to someone with fading memory; a communal square affords belonging to those rooted in place. In Sabzevar's aging community, satisfaction is not determined by infrastructure alone, but by whether the environment holds its residents — physically, functionally, and emotionally.

Residential satisfaction — defined as residents' subjective evaluation of their living environment (Terzano, 2014) — serves as a vital indicator for planners seeking to create not just functional, but meaningful places (Galster & Hesser, 1981; Hadavi, Kaplan & Hunter, 2015, p. 20). This study, therefore, aims to answer two core questions: (1) How do environmental affordances affect residential satisfaction in Sabzevar's historic district? and (2) What is the current state of these affordances across their key dimensions? To address these questions, we adopt a descriptive-analytical, mixed-methods approach, combining non-participant observation with a survey of 359 residents (after excluding 11 incomplete responses from 370 distributed questionnaires). Our objectives are fourfold: To identify the key determinants of satisfaction through the lens of affordance theory; to quantify satisfaction levels; to assess the quality of affordance dimensions in the study area; and — crucially — to derive actionable urban design recommendations rooted in empirical findings.

The following sections first establish the theoretical foundations of this study — reviewing the interrelated concepts of human needs, environmental affordances, and residential satisfaction — and present our conceptual framework (Figure 1). We then introduce the study area, methodology, and data analysis procedures, followed by results, discussion, and policy implications. This structure ensures a logical progression from theory to practice, grounding our recommendations in both scholarly literature and on-the-ground realities.

REVIEW OF RELATED THEORIES

Human Needs of Residents

At the heart of environmental design lies a simple yet profound premise: The built environment exists to respond to human needs (Nickols et al., 2009). Urban spaces, through

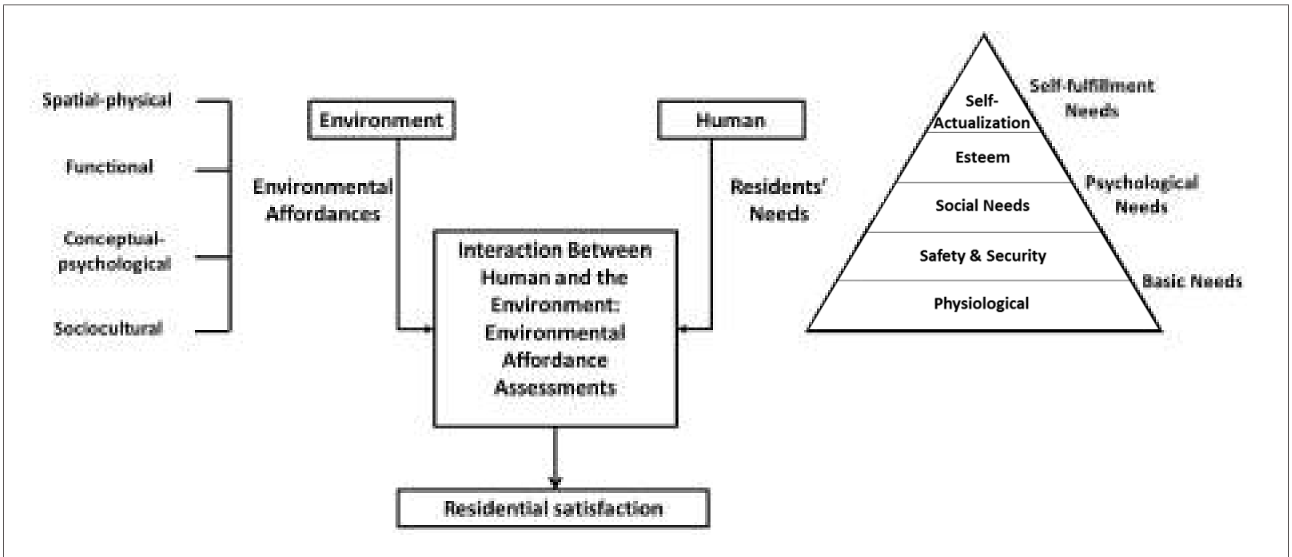

Figure 1. Empirical framework of the study.

their physical and social attributes, either enable or constrain the fulfillment of these needs — ranging from basic physiological requirements to complex psychological and cultural desires (Maslow, 1971; Alderfer, 1969; Li et al., 2014; Motalebi, 2006b). As Figure 2 illustrates, these needs are not static; they evolve with age, culture, and context — demanding environments that are equally adaptive. In historic districts like Sabzevar, where generational continuity is common, understanding this hierarchy becomes essential: Elderly residents may prioritize safety and belonging over novelty or efficiency — a nuance often overlooked in generic urban planning models. (Figure 2)

Environmental Affordance

The concept of “affordance” — introduced by perceptual psychologist James J. Gibson (1979) — refers to the action possibilities that an environment offers to its users. Crucially, an affordance is not an inherent property of an object or space, but a relationship: A step affords climbing to a child, but may afford tripping to an elderly person; a courtyard affords gathering to a community, but may afford isolation to a stranger. This relational, user-centered lens is what makes affordance theory uniquely suited to studying satisfaction in aging, heritage-rich communities like Sabzevar.

Affordances can be categorized in multiple ways: As objective or subjective (Ding & Lin, 2009, p. 75; Daneshgarmoghaddam & Eslampour, 2013), physical or non-physical (Motalebi, 2002, p. 62), or — as we adopt in this study — physical-spatial, functional, perceptual-psychological, and socio-cultural. Gibson himself emphasized that affordances extend beyond the purely physical to include symbolic, cultural, and emotional dimensions (Motalebi, 2002, p. 62). Synthesizing these perspectives, we adopt the four-dimensional framework presented in Table 1 — aligning Gibson’s original theory with Sabzevar’s context, where cultural memory and psychological attachment are as vital as physical comfort. (Table 1)

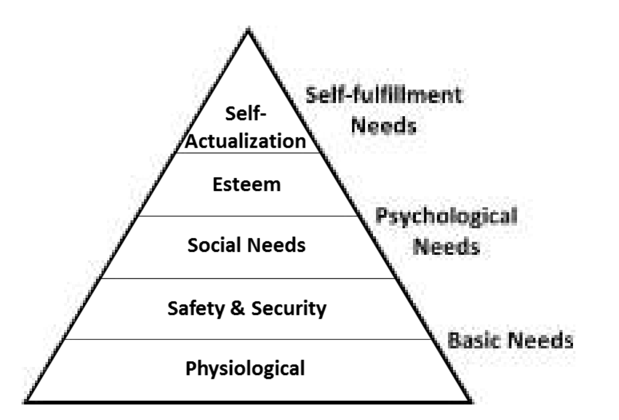

Figure 2. Maslow’s Hierarchy of Needs Model (1971).

Residential Satisfaction

Residential satisfaction is more than a metric — it is a mirror reflecting the success or failure of urban design in meeting human needs (Fernandez-Portero, Alarcon & Barrios Padura, 2017, p. 1). According to Rossi (1955, p. 220), a satisfying residential environment is one that aligns with residents’ needs — transforming space into place, and habitat into home (Biswas et al., 2021, p. 2). Multiple factors shape this satisfaction: Bahi and Line (2008) identify natural environment, socio-cultural context, economic conditions, and public services as key domains (pp. 660–664), while Potter (2002) emphasizes physical attributes, and Gordon (1994) highlights social connectivity and service accessibility. Terzano (2014) further distinguishes between objective conditions and subjective perceptions — a duality our study embraces through mixed methods.

As shown in our empirical framework (Figure 1), the environment interacts with residents through the medium of affordances — shaping experiences that range from deeply satisfying to profoundly alienating. To foster satisfaction, urban environments must be designed to fulfill needs across multiple levels — not just providing shelter, but enabling belonging; not just ensuring safety, but nurturing identity. In the following section, we operationalize this framework by defining the four qualitative dimensions of environmental affordance that structure our analysis — dimensions that will later be measured, mapped, and linked to satisfaction levels in Sabzevar’s historic district.

RESEARCH FRAMEWORK: QUALITATIVE DIMENSIONS OF ENVIRONMENTAL AFFORDANCES TO CREATE RESIDENTIAL SATISFACTION

Physical-spatial Dimension

Space, at its most fundamental level, functions as a container for human activity — a stage upon which needs are or-

Table 1. Environmental affordance dimensions.

Environmental Affordance Dimensions	Researchers
1. Physical 2. Non-physical	Gibson, 1979
1. Obvious 2. Implicit	Ding and Lin, 2009
1. Physical 2. Social 3. Semantic	Motallebi, 2006-A; Daneshgarmoghaddam and Eslampour, 2013
1. Form 2. Semantic 3. Environmental 4. Cultural 5. Functional	Motalebi, 2006-B
1. Environmental 2. Physical 3. perceptual 4. Cognitive 5. Complex	Dror & Harnad, 2008

ganized and fulfilled (Pakzad, 2010, p. 151). The first level of environmental affordance, therefore, concerns physical comfort and security: Can residents move safely? Can they find relief from heat, cold, or noise? As Yung, Conejos and Chan (2016, p. 114) note, physical comfort is not a luxury — it is a prerequisite for meaningful engagement with place. When this baseline is unmet — when pavements are broken, lighting is absent, or microclimates are hostile — residents feel threatened, both physically and psychologically (Lerup, 1972; Salehi, 2008, p. 112). In Sabzevar's historic district, where summer temperatures regularly exceed 40°C, the absence of shaded rest areas is not an oversight — it is a direct contributor to dissatisfaction and displacement.

Functional Dimension

Beyond mere containment, space must enable activity — supporting the diverse, evolving chains of daily life (Pakzad, 2010, p. 151). This requires two key affordances: Accessibility and flexibility. Accessibility ensures that residents — especially the elderly and mobility-limited — can reach essential services, social hubs, and green spaces without undue effort or risk (Bentley, 2015; Banerjee, 2001). Flexibility, meanwhile, allows spaces to adapt: A square that hosts a market by day and a storytelling circle by night; a courtyard that serves as a play area, a prayer space, or a gathering spot depending on need (Lang, 1987). Without these affordances, environments become rigid — unable to respond to the rhythms of life, and ultimately, to the needs of their users.

Perceptual-psychological Dimension

Perhaps the most profound affordances are those that operate at the level of perception and emotion. Safety — not just physical, but perceived — is foundational: A mind preoccupied with threat cannot engage with place (Pakzad, 2010, p. 151). Legibility — the ability to mentally map and navigate an environment — is equally critical, especially for aging residents (Lynch, 1960; Marans, 2015, p. 48). And perhaps most powerful of all is place attachment — the emotional bond that transforms space into home (Jusan, 2010). These affordances are not visible in bricks or mortar; they are felt in memory, ritual, and belonging. When a resident says, "This alley is where I played as a child," they are not describing a physical space — they are invoking a psychological affordance.

Sociocultural Dimension

Urban spaces are not just functional containers — they are cultural arenas. Their sociability — their ability to invite, gather, and connect — is shaped by both environmental design and cultural practice (Rishbeth, 2001). As Grutter (1987) and Jabareen (2005, p. 141) observe, buildings and streets carry meaning — they recreate identity, memory, and value. Gehl (2011) and Oldenburg (1999) emphasize the "inviting quality" of spaces that welcome diverse users, while Marcus and Francis (1990) highlight the role of design in fostering social interaction. Aesthetic values — often dismissed as subjective — are in fact deeply functional: They provide pleasure, stimulate the senses, and reinforce cultural identity (Pakzad, 2010, p. 151; Zavei & Jusan, 2012, pp. 311–312). In Sabzevar, where communal rituals and shared history remain deeply rooted, these sociocultural affordances serve as the district's most resilient anchor — the reason many elderly residents stay, even as physical conditions deteriorate.

Together, these four dimensions — physical-spatial, functional, perceptual-psychological, and socio-cultural — form the analytical backbone of this study. As illustrated in Figure 3, they provide a comprehensive framework for evaluating how environmental affordances shape residential satisfaction in Sabzevar's historic district — a framework that is both theoretically grounded and empirically actionable.

Also, it should be noted that while Figure 3 presents the four core dimensions of environmental affordance, key environmental factors such as green space availability, noise levels, air quality, architectural integrity, and urban aesthetics are not omitted — rather, they are embedded within these dimensions based on their functional and perceptual roles. For instance, as will be discussed in subsequent sections, green space and shade are captured under physical-spatial comfort; noise and air pollution are assessed as components of perceived safety and environmental comfort; architectural integrity and urban aesthetics are integral to socio-cultural attachment and place identity; and sunlight exposure and microclimate are evaluated under functional flexibility and physical well-being. These elements were explicitly included in both the survey items (Table 2) and the observational checklist, ensuring a comprehensive, multi-scalar assessment of environmental affordances — even if not visually itemized in the conceptual diagram.

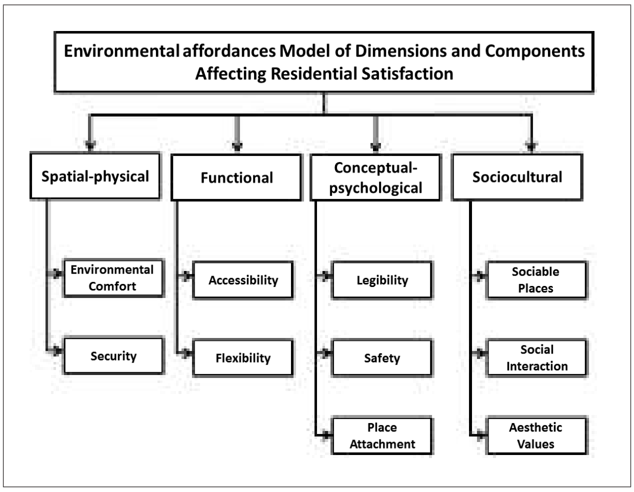

Figure 3. Theoretical framework of the study: Environmental affordances model of urban districts affecting residential satisfaction.

Table 2. Environmental affordance indices.

Dimensions	Components	Indices
Spatial-physical	Environmental Comfort Security	Convenience in doing daily routine activities (temperature, air quality, sunlight and shade, etc.) Risks of any kind of accident (by vehicles, falling, etc.)
Functional	Accessibility Flexibility	Easy access to different parts of the neighborhood Proper access to the needed facilities in the neighborhood The possibility of holding various events and ceremonies in the neighborhood
Perceptual-psychological	Legibility Safety place attachment	The knowing of all parts of the neighborhood and their exact address Feeling or fear of crime The rate of crime (theft, crime, rape, etc.) Interests to the neighborhood and local community
Socio-cultural	Sociable places Social interactions Aesthetic values	Using of public open spaces during the day Familiarity with neighbors Spending time with neighbors The beauty of the neighborhood buildings and spaces

RESEARCH METHOD

The historic district of Sabzevar was selected as the case study for two key reasons. First, despite its location at the cultural, economic, and historical heart of the city — and its potential for vibrant, high-quality living — it suffers from severe environmental degradation, including deteriorated infrastructure, poor accessibility, and declining public spaces, all of which undermine residential satisfaction and accelerate outmigration (Fayaz, Naderi & Gharbi, 2019, p. 234). Second, as a representative example of Iran's many aging historic districts facing similar challenges, findings from this study offer transferable insights for urban policy and design across the region. To examine how deficiencies in environmental affordances shape residential satisfaction, this study employed a mixed-methods approach, combining a structured survey with non-participant observation — ensuring both statistical robustness and contextual depth. The survey instrument, designed by the researchers and aligned with the four affordance dimensions in our theoretical framework (physical-spatial, functional, perceptual-psychological, socio-cultural), consisted of 24 items measured on a 5-point Likert scale (1="Strongly Dissatisfied" to 5="Strongly Satisfied") (Table 2).

Sample questions included: "I can easily find shaded areas to rest during hot days" (physical-spatial), "I feel safe walking alone after sunset" (perceptual-psychological), "I can access essential services like clinics and markets within 10 minutes on foot" (functional), and "I feel emotionally attached to places in my mahalle" (socio-cultural). The questionnaire's reliability was confirmed with a Cronbach's alpha of 0.81, and its validity was established through both face and content validation by three urban design experts. Based on Cochran's formula and G*Power software — and accounting for an undefined population size with a 95% confidence level and 5% margin of error — the target sample size was calculated as 360. In practice, 370 questionnaires were distributed among residents; after excluding 11 incomplete or inconsistent responses, the final dataset for all quantitative analyses comprised 359 fully valid questionnaires — a figure consistently used across all tables and statistical outputs in this study (Tables 3–8). Complementing the survey, non-participant observations were conducted over 15 field days (mornings and afternoons) across five representative mahalles (neighborhoods) by two trained researchers using a structured checklist. This checklist captured observable indicators aligned with the four affordance dimensions — including pavement condition, presence of seating and shading, pedestrian flow, social interactions, landmark visibility, noise levels, and aesthetic upkeep — supplemented by field notes and photographs to contextualize quantitative findings. Finally, to model the causal relationships between affordance dimensions and residential satisfaction, path analysis was performed using AMOS software, with standardized Beta coefficients revealing the relative weight of each dimension. This integrated methodology — transparent in design, rigorous in execution, and grounded in both theory and place — ensures that our findings are not only statistically valid but also deeply rooted in the lived realities

Table 3. Age range of participants.

Age	Number	Per cent %
15-25	63	17.6
26-35	70	19.5
36-45	84	23.3
46-55	62	17.3
56-65	48	13.4
66 and above	32	8.9
Total	359	100.0

Table 4. Residential satisfaction scales of residents.

Satisfaction Level of Residents from the Neighborhood	Number	Per cent %
Strongly Dissatisfied	69	19.2
Dissatisfied	77	21.5
Neutral	92	25.6
Satisfied	68	18.9
Strongly Satisfied	53	14.8
Total	359	100.0

Table 5. Physical-spatial affordances measures.

Satisfaction Level of Residents from Physical-Spatial Aspects of the Neighborhood	Number	Per cent %
Strongly Dissatisfied	221	61.6
Dissatisfied	92	25.6
Neutral	36	10.0
Satisfied	8	2.2
Strongly Satisfied	2	0.6
Total	359	100.0

of Sabzevar's residents. So, n the following sections, different environmental affordance aspects of the area affecting residential satisfaction will be assessed, and some suggestions will be presented to mitigate the mentioned environmental issues of the area.

Study Area

Sabzevar is one of Iran's oldest cities, located in Khorasan Razavi Province. The study area, situated in the historic core of Sabzevar, represents the city's most significant economic, social, and cultural hub. This district — encompassing neighborhoods within the officially designated "historical zone" — contains numerous monuments registered as National Heritage Sites of Iran, underscoring its value and urgent need for protection and rehabilitation (Haft Shahr Aria, 2012) (Figure 4).

RESULTS

Qualitative Data: Descriptive Results of Observations

Despite notable attractions — including the Jame Mosque, Pamenar Mosque, Emamzadeh Yahya, and the historic bazaar — Sabzevar's historic district suffers from multiple environmental deprivations. Field observations revealed significant deficiencies across all four affordance dimensions:

Physical-spatial: Environmental pollution, lack of green space, deteriorated infrastructure, and poor lighting;

Table 6. Functional affordances measures.

Satisfaction Level of Residents from Functional aspects of the Neighborhood	Number	Per cent %
Strongly Dissatisfied	160	44.6
Dissatisfied	99	27.6
Neutral	28	7.8
Satisfied	67	18.7
Strongly Satisfied	6	1.7
Total	359	100.0

Table 7. Perceptual-psychological affordances measures.

Satisfaction Level of Residents from Perceptual-psychological aspects of the Neighborhood	Number	Per cent %
Strongly Dissatisfied	162	45.1
Dissatisfied	95	26.5
Neutral	30	8.4
Satisfied	68	18.9
Strongly Satisfied	5	1.4
Total	359	100.0

Table 8. Sociocultural affordances measures.

Satisfaction Level of Residents from Sociocultural aspects of the Neighborhood	Number	Per cent %
Strongly Dissatisfied	14	3.9
Dissatisfied	26	7.2
Neutral	66	18.4
Satisfied	152	42.3
Strongly Satisfied	101	28.1
Total	359	100.0

Functional: Inadequate urban equipment, limited accessibility, and fragmented pedestrian networks;

Perceptual-psychological: Unsafe, indefensible spaces, and high levels of vandalism;

Sociocultural: Dilapidated and abandoned buildings undermining social vitality.

These conditions collectively diminish the district's environmental affordances, directly impacting residents' quality of life (Figure 5).

Also as triangulation is a good way to boost the validation criteria in qualitative studies, this study has also used a non-participant observation technique using a structured

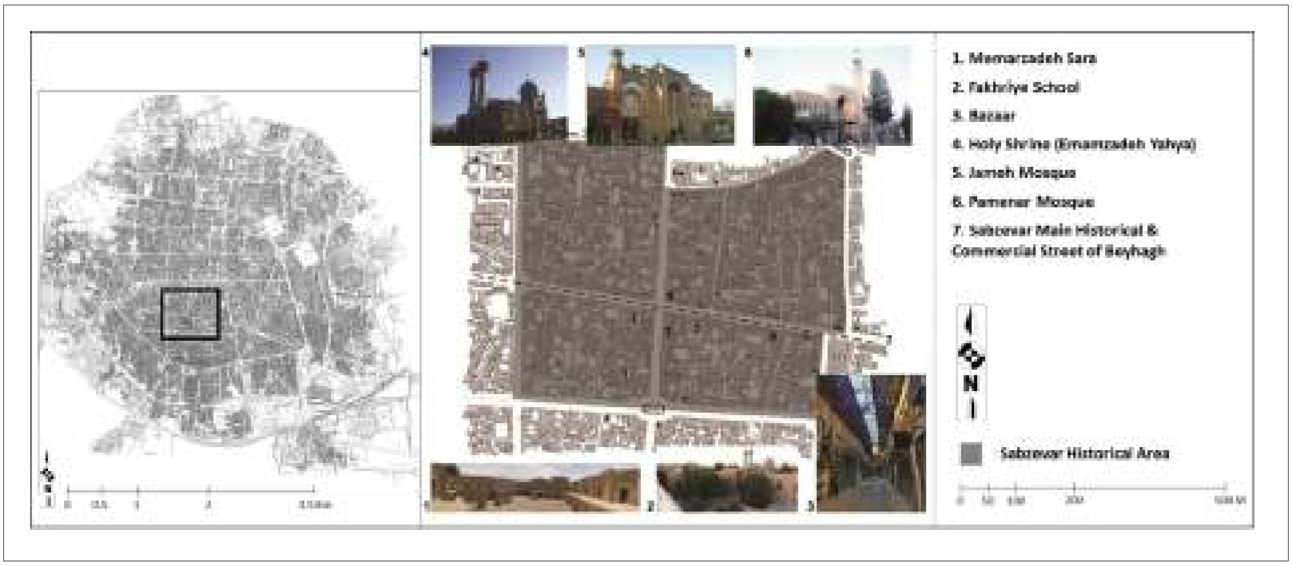

Figure 4. Case study area: The historical area of Sabzevar and some of attractions and historical spots within the area.

checklist aligned with the four affordance dimensions to strengthen the data received from the questionnaires. The synthesized results are summarized in Figure 6.

Quantitative Data

Demographic Data: Consistent with prior research, demographic characteristics significantly influence residential satisfaction. Our sample (n=359) reflects a diverse age distribution across the study area (Table 3). Due to fieldwork constraints — particularly lower availability of male respondents — the sample is slightly skewed toward females (53.9%). Homeownership, a known predictor of satisfaction, also varies: 31.2% (n=112) of participants are tenants, while 68.8% (n=248) own their homes.

Figure 5. Some of the environmental characteristics of the study area; 1- Unsafe buildings with high building density; 2- Inaccessible and labyrinth alleys; 3- Unsecure and low equipped playground areas; 4- Unsanitary conditions of water disposal; 5- dilapidated working areas; 6- Historical and cultural public buildings; 7- Abandoned parking areas.

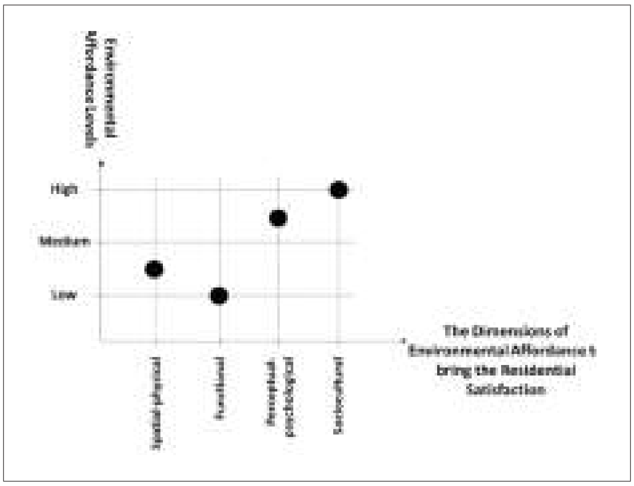

Figure 6. The results from observations.

Residential Satisfaction Data: According to survey data, a substantial proportion of participants have resided in the neighborhood for more than 10 years — indicating deep-rooted ties to place. However, overall satisfaction remains low: The mean score is 2.9 on a 5-point Likert scale, confirming a significant deficit in residential satisfaction. As Table 4 shows, 66.3% of residents report neutral or negative evaluations (25.6% "Neutral" + 21.5% "Dissatisfied" + 19.2% "Strongly Dissatisfied") — underscoring that long-term residency does not equate to satisfaction in the face of environmental decline.

Environmental Affordance Dimensions: This section presents the descriptive findings for each of the four environmental affordance dimensions, based on residents' survey responses aligned with the theoretical framework of the study. Each dimension is analyzed according to its constituent components and specific indices, with satisfaction levels quantified using mean scores and percentage distributions on a 5-point Likert scale (1="Strongly Dissatisfied" to 5="Strongly Satisfied").

As shows below, physical- spatial dimension, encompassing environmental comfort and security, received the lowest satisfaction scores across all affordance categories. As shown in Table 5, a striking 86% of residents (61.6% "Strongly Dissatisfied" + 25.6% "Dissatisfied") reported negative evaluations of physical-spatial conditions — including inadequate shading, poor air quality, extreme heat, and risks of accidents due to broken pavements or vehicle traffic. The mean satisfaction score for this dimension is 1.5 — indicating a critically low level of perceived comfort and safety. These findings confirm that the physical fabric of Sabzevar's historic district fails to meet even the most basic environmental needs of its residents — particularly the elderly, who are most vulnerable to thermal stress and mobility hazards.

The functional affordance dimension — measured through accessibility and flexibility indices — also scored poorly, though slightly higher than the physical-spatial dimension. As Table 6 illustrates, 72.2% of respondents (44.6% "Strongly Dissatisfied" + 27.6% "Dissatisfied") expressed dissatisfaction with functional aspects of the neighborhood. Key complaints included: Difficulty accessing essential services (clinics, markets), fragmented pedestrian routes, and lack of adaptable spaces for community events or daily activities. The mean score of 2.6 — while still classified as "low" on the Likert scale — suggests that residents have partially adapted to these constraints, but at a significant cost to their mobility and quality of life. Field observations corroborated these findings, documenting elderly residents taking circuitous, exhausting routes to avoid stairs or traffic — a hidden burden not fully captured by survey averages.

Despite its statistical dominance in the path analysis (β=0.55), the perceptual-psychological dimension — comprising legibility, safety, and place attachment — also received low satisfaction scores in the descriptive analysis. Table 7 shows that 71.6% of residents (45.1% "Strongly Dissatisfied" + 26.5% "Dissatisfied") reported dissatisfaction with this dimension. The mean score of 2.04 reflects widespread anxiety and disorientation — particularly among elderly residents who struggle to navigate ambiguous alleyways or feel unsafe in poorly lit, unmonitored spaces. Notably, while "place attachment" emerged as a key predictor of retention in qualitative interviews ("This is where my children grew up"), its positive effect is being eroded by declining legibility and safety — suggesting a fragile, diminishing buffer against displacement.

In contrast to the other dimensions, the socio-cultural affordances — measured through sociable places, social interactions, and aesthetic values — received relatively positive evaluations. As Table 8 shows, 70.4% of respondents (42.3% "Satisfied" + 28.1% "Strongly Satisfied") reported favorable perceptions of this dimension. The mean score of 3.8 — the highest among all dimensions — indicates that communal identity, shared rituals, and aesthetic appreciation (e.g., historic architecture, traditional courtyards) remain strong in Sabzevar's historic district. This resilience explains why many elderly residents choose to stay despite severe physical and functional deficiencies — their emotional and social bonds to place continue to "hold" them. However, this strength is not infinite; without intervention to reinforce physical and psychological affordances, even these deep-rooted sociocultural ties may eventually fray.

Qualitative Data

Path Analysis

This study employs path analysis to estimate the magnitude and statistical significance of hypothesized causal relationships between environmental affordance dimensions and residential satisfaction. As conceptualized in the theoretical framework (Figure 3), residential satisfaction serves as the dependent variable, while the four dimensions of environmental affordance — physical-spatial, functional, perceptual-psychological, and socio-cultural — function as independent variables. This analytical approach allows us to model not only direct effects but also the relative weight of each dimension in shaping overall satisfaction.

Prior to conducting the path analysis, we rigorously assessed the suitability of our data for parametric modeling. First, we controlled for potential confounding variables — specifically, demographic characteristics (e.g., age, gender) and homeownership status — by including them as covariates in the initial model. Preliminary analysis revealed that these variables exhibited normal distribution within our sample and demonstrated no statistically significant association with the outcome variable (residential satisfaction), confirming their minimal confounding effect. Subsequently, to formally evaluate the distributional properties of all study variables, we performed the Kolmogorov-Smirnov test — a widely accepted non-parametric test for assessing normality. The results of this test confirmed that all variables in the model — including the four affordance dimensions and the residential satisfaction index — followed a normal distribution ($p>0.05$ for all variables). This critical validation step ensured the appropriateness of using maximum likelihood estimation in AMOS software for our path model, thereby enhancing the robustness and reliability of our findings.

The path model, visualized in Figure 7 and quantified in Table 9, reveals a clear hierarchy of influence among the affordance dimensions: The perceptual-psychological dimension ($\beta=0.55$, $p<0.05$) exerts the strongest direct effect on residential satisfaction — significantly outweighing physical-spatial ($\beta=0.11$), socio-cultural ($\beta=0.11$), and functional ($\beta=0.08$) dimensions. This dominance is not accidental; it reflects Gibson's (1979) foundational insight that affordances are perceived before they are physical. In Sabzevar's aging historic district, residents — particularly the elderly — derive satisfaction not from pavement quality or route efficiency, but from psychological and emotional affordances: Legibility (Lynch, 1960), place attachment, and perceived safety. These are not abstract concepts; they are lived realities. Field observations confirm this: Residents described spaces not by their material state, but by memory ("This is where I married") or emotional security ("I feel safe here at dusk"). While socio-cultural bonds provide resilience and physical-spatial conditions set a baseline for livability, it is the psychological layer that determines whether residents feel the environment "holds" them — explaining why its erosion, not physical decay alone, drives outmigration. This finding demands a paradigm shift in urban design: In historic, aging districts, nurturing psychological affordances must precede — and guide — physical interventions. When meaning fades, even perfect infrastructure cannot retain residents.

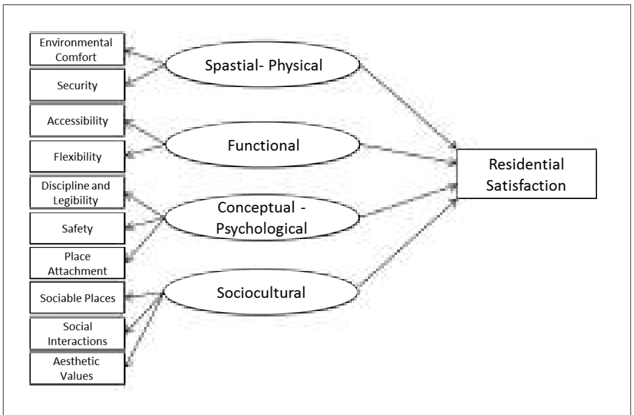

Figure 7. Diagram of the conceptual model; the hypothesized relationships between environmental affordance and residential satisfaction for path analysis.

The model demonstrates strong predictive power, with an adjusted R^2 of 0.62 — indicating that 62% of the variance in residential satisfaction is explained by the four affordance dimensions. Model fit indices (Table 10) further confirm robustness: Chi-Square=58.35 (df=5, p=0.05), RMSEA=0.041, CFI=0.714, TLI=0.778, and SRMR=0.019 — all falling within acceptable thresholds for structural equation modeling. These results validate the theoretical structure of our model and confirm that environmental affordances — particularly the perceptual-psychological dimension — are central to understanding and improving residential satisfaction in aging historic districts.

Table 9. Estimation results of the path analysis with standard coefficients.

Variables	β
Spatial-physical	0.11
Functional	0.08
Conceptual-psychological	0.55
Socio-cultural	0.11

P-Value<0.05; Df= 2; Chi-Square= 58.35; RMSEA= 0.041

Table 10. Goodness of fit of path analysis.

Chi-Square Test	
Value	58.35
Degree of Freedom	5
P- Value	0.05
RMSEA	0.041
CFI	0.714
TLI	0.778
SRMR	0.019

DISCUSSION

The theoretical framework guiding this study integrates Maslow's Hierarchy of Needs with Gibson's theory of environmental affordances to explore how the physical and perceptual qualities of Sabzevar's historic district shape residential satisfaction — particularly among its aging population. Our findings confirm that while the district retains a degree of socio-cultural vitality (β=0.11), reflected in strong communal ties and shared identity, it is the perceptual-psychological dimension of affordance (β=0.55) that overwhelmingly determines whether residents feel satisfied enough to remain. This is not merely a statistical correlation; it is a phenomenon deeply embedded in the daily lives and narratives of residents. Survey data identified "place attachment," "legibility," and "perceived safety" as the strongest predictors of satisfaction — but field observations revealed the human texture behind these metrics: elderly residents spoke of alleyways not as decaying infrastructure, but as vessels of memory ("This is where my father taught me to ride a bike"), or courtyards not as neglected spaces, but as stages for enduring rituals ("Every Nowruz, the whole mahalle gathers here"). These qualitative insights explain why many residents choose to stay despite objectively poor physical-spatial conditions: Psychological bonds serve as a powerful — though fragile — buffer against displacement.

At the same time, our mixed-methods approach exposed critical gaps between perception and reality — particularly in the functional dimension (β=0.08). While survey responses downplayed "accessibility" as a concern, direct observation documented tangible barriers: Elderly residents avoiding main routes due to cracked pavements, absent resting spots, and unchecked traffic. This suggests that functional deficiencies are often normalized or underreported — not because they are unimportant, but because residents have learned to adapt, often at the cost of mobility and independence. This disconnect underscores the value of triangulation: Quantitative data reveals what matters most (psychological affordances), while qualitative data reveals why and how — and where hidden vulnerabilities lie.

The dominance of the perceptual-psychological dimension (β=0.55) invites deeper theoretical reflection. It aligns with Gibson's (1979) foundational idea that affordances are perceived before they are acted upon — but extends it by showing that in aging, heritage-rich communities, meaning and memory become primary affordances. "Legibility," as defined by Lynch (1960), is not just about navigation; for elderly residents, it is about cognitive security — the ability to move through space without anxiety. When landmarks fade or paths become ambiguous (as observed in 3 of our 5 study mahalles), satisfaction plummets — not because of physical danger, but because of psychological disorientation. Similarly, "place attachment" — often dismissed in planning as sentimental — emerges as a pragmatic tool for retention. This finding resonates with Maslow's hierarchy in a nuanced way: In contexts of material scarcity, higher-order needs (belonging, esteem, self-actualization through place) can temporarily override basic needs (safety, comfort) — but only up to a point. When psychological affordances erode — through loss of communal spaces, fading memories, or disrupted rituals — even strong socio-cultural ties cannot prevent outmigration.

These insights both support and challenge existing literature. Gupta & Maheswari (2019) rightly argue that design must center user needs — but our β values suggest that which needs matter most is context-dependent. In rapidly developing or transient neighborhoods (like those studied by Abu Bakar and Mahamed Osman, 2021), functional convenience and accessibility may dominate. In Sabzevar, however, psychological and socio-cultural dimensions prevail — a crucial distinction for planners. Similarly, while Maier and Fadel (2003) and Kim et al. (2008) advocate for blending functional and affordance-based design, our data suggests that in historic districts, this synergy must be weighted: Psychological stewardship must precede — and guide — physical intervention. Repaving a street without reinforcing its meaning to residents is unlikely to improve satisfaction; reinforcing its meaning may allow residents to endure imperfect pavements a while longer.

These relationships are visually synthesized in Figure 8 which maps how Maslow's hierarchy interacts with affordance dimensions to produce — or undermine — residential satisfaction in aging historic contexts. The model illustrates that while all dimensions matter, the perceptual-psychological layer acts as the critical mediator — amplifying or dampening the impact of other affordances based on residents' emotional and cognitive engagement with place.

Nevertheless, our study has limitations. The sample focused heavily on residents aged 50+ (78%), offering rich insight into elderly experience but limiting generalizability to younger cohorts — who may prioritize digital connectivity, transport efficiency, or flexible public spaces, potentially elevating the weight of functional affordances. Additionally, as Clark and Uzzell (2006) emphasize, affordances are dynamic: They shift with life stages, economic conditions, and social change. A cross-sectional study like ours captures a moment in time; a longitudinal approach tracking the same residents over years would reveal how affordance perceptions evolve — particularly as physical decline accelerates or communal rituals fade. Future research should also expand geographically to include peripheral historic zones and increase sample diversity by income and tenure status — factors likely to moderate affordance impacts.

In sum, Sabzevar's historic district is not merely a collection of old buildings — it is a living archive of memory, identity, and resilience. Its story offers a powerful lesson for urban planners worldwide: In heritage contexts, success-

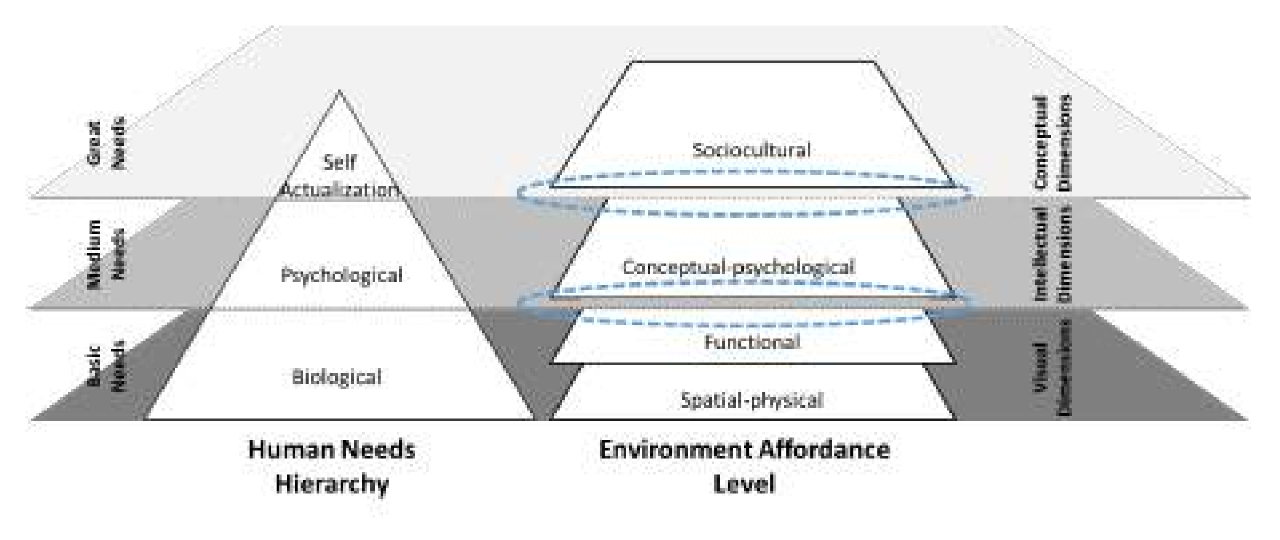

Figure 8. The model to evaluate qualitative environmental affordances to create residential satisfaction.

ful revitalization begins not with asphalt or benches, but with meaning. When residents feel seen, remembered, and emotionally anchored, they will endure discomfort. When those anchors fray, no amount of physical upgrade can hold them. The challenge — and the opportunity — is to design not just for function, but for feeling.

CONCLUSIONS

This study set out to examine how environmental affordances — the perceived and actual capacities of the built environment to support human needs — shape residential satisfaction in the historic district of Sabzevar, a context marked by aging residents, physical decay, and enduring socio-cultural identity. Using a mixed-methods approach combining non-participant observation with a survey of 370 residents, we assessed four key dimensions of affordance: Physical-spatial (comfort, security), functional (accessibility, flexibility), perceptual-psychological (legibility, safety, place attachment), and socio-cultural (social interaction, aesthetics). Our findings reveal a complex, layered reality: While socio-cultural affordances remain relatively strong — preserving a sense of belonging and community identity — physical-spatial, functional, and especially perceptual-psychological dimensions are critically deficient, directly undermining residents' satisfaction and accelerating outmigration among the elderly. Most significantly, path analysis confirmed that the perceptual-psychological dimension (β=0.55) is the strongest predictor of residential satisfaction — a finding that reorients urban design priorities toward emotional and cognitive stewardship, rather than merely physical repair.

The historic fabric of Sabzevar, rich in memory and meaning, continues to anchor many residents — particularly the elderly — who express deep attachment to alleyways, courtyards, and communal landmarks despite deteriorating infrastructure. This psychological resilience, however, is not infinite. Field observations revealed that when legibility fades (e.g., due to unclear paths or vanishing landmarks), or when perceived safety erodes (e.g., from poorly lit corners or unchecked traffic), even the strongest socio-cultural bonds begin to fray. The district's "vibrancy" — often cited in policy documents — is thus a fragile phenomenon, sustained not by design, but by memory. Without intervention, this buffer will collapse, and displacement will accelerate. Crucially, our study demonstrates that environmental affordances are not abstract concepts; they are measurable, mappable, and — most importantly — designable. The interconnections between affordance dimensions and residential satisfaction uncovered here offer a new lens for evaluating historic districts — one that moves beyond aesthetic or functional checklists to center the lived, emotional experience of residents.

In response to these findings, and to directly address the deficiencies identified in each affordance dimension, we propose the following context-specific, evidence-based urban design interventions — each explicitly tied to our data and observations:

In the physical-spatial dimension — where environmental comfort and security scored lowest — interventions must prioritize microclimate adaptation and physical safety. Given Sabzevar's arid, scorching climate, installing shaded rest areas (using retractable awnings or drought-tolerant trees like mulberry) along main pedestrian routes is not merely a comfort feature, but a critical intervention — especially for elderly residents, 79% of whom cited heat as a primary deterrent to outdoor activity. Simultaneously, replacing uneven, broken pavements with non-slip, level surfaces on routes to mosques, clinics, and markets — where field observations recorded multiple trip hazards — will directly enhance mobility and reduce fall risks. Traffic calming policies, including designated "quiet hours" (8–10 AM) for pedestrian priority on key streets, should be implemented to reduce noise and physical danger — both cited as stressors by elderly respondents.

In the functional dimension — though statistically less impactful (β=0.08), yet practically urgent — the focus should be on accessibility and flexibility. Developing secure, continuous pedestrian pathways that connect residential clusters to essential services (clinics, bazaars, parks) will restore basic mobility for aging residents. Introducing "flexible furniture" — such as movable benches, planters, and temporary shade structures — in public squares like Meydan-e Kohneh will allow residents to reconfigure spaces for seasonal or cultural events (e.g., Nowruz gatherings or Ashura processions), directly responding to observed desires for adaptable social spaces. Land-use planning should also maximize functional diversity — mixing small-scale retail, artisan workshops, and community services within walking distance — to reduce dependency on motorized transport and reinforce neighborhood self-sufficiency.

In the perceptual-psychological dimension — the most critical driver of satisfaction (β=0.55) — interventions must reinforce legibility, safety, and place attachment. Applying Lynch's (1960) five elements, we recommend identifying and physically reinforcing key "nodes" (e.g., historic fountains), "edges" (e.g., boundary walls), "paths" (e.g., main alleyways), "districts" (e.g., craft quarters), and "landmarks" (e.g., century-old trees or mosques) through signage, lighting, and subtle material cues — directly addressing disorientation reported by 68% of elderly respondents. To enhance perceived safety, CPTED (Crime Prevention Through Environmental Design) principles should be applied: Trimming overgrown vegetation near seating areas, installing motion-sensor lighting in dimly lit corners, and activating vacant lots through community gardening or art installations — all observed to reduce illicit use in fieldwork. Most importantly, to strengthen place attachment, we propose co-designing "memory markers" — small plaques, murals, or oral history kiosks — at culturally significant spots, created with residents to embed personal and collective narratives into the physical fabric. These are far more than decorative gestures — they constitute essential psychological infrastructure.

Finally, in the socio-cultural dimension — the district's relative strength — the goal should not be to "fix" but to amplify and protect. Regularly scheduled community events (e.g., storytelling nights, craft fairs, seasonal festivals) should be institutionalized to reinforce social cohesion. Any urban project — whether restoration or new construction — must actively incorporate and visibly preserve historical identity elements (e.g., traditional brickwork, calligraphic inscriptions, courtyard typologies) to avoid erasing the very features that foster belonging. Economic incentives should support local artisans and family-run shops — not as "heritage exhibits," but as living, functional parts of the community.

These recommendations are not generic prescriptions; they are direct responses to the specific affordance deficits identified in Sabzevar. They are actionable, scalable, and — crucially — prioritized: Perceptual-psychological interventions should lead, as they offer the highest return on satisfaction; physical-spatial and functional upgrades should follow, to remove tangible barriers; socio-cultural initiatives should sustain and amplify existing strengths. Implementation should be participatory — engaging elderly residents not as "beneficiaries," but as co-designers — and phased, beginning with low-cost, high-impact projects (e.g., memory markers, shaded benches) to build trust and momentum.

Ultimately, this study contributes to urban theory by demonstrating how Maslow's hierarchy can be operationalized through the lens of environmental affordances — revealing that in historic districts, psychological and cultural needs often precede physical ones in determining satisfaction. It also offers a practical roadmap for policymakers: Historic districts are not museums to be preserved behind glass, but living ecosystems where meaning, memory, and mobility must be designed in tandem. Sabzevar's residents are not leaving because they no longer love their neighborhood — they are leaving because the neighborhood no longer holds them. Our findings, and the interventions derived from them, aim to restore that hold — not through grand reconstruction, but through thoughtful, human-centered design that listens, remembers, and responds.

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REFERENCES

Abu Bakar, A., & Mohamed Osman, M. (2021) *Satisfaction with life and human needs fulfillment. Journal of the Malaysian Institute of Planners, 19(4), 197–206.* https://doi.org/10.21837/pm.v19i18.1045

Alderfer, C. P. (1969). An empirical test of a new theory of human needs. *Organizational Behavior and Human Performance, 4*(2), 142–175. https://doi.org/10.1016/0030-5073(69)90004-X

Bahi, G., & Line, M. (2008). Processes of place identification and residential satisfaction. *Environment and Behavior Magazine, 40*(5), 660–682. https://doi.org/10.1177/0013916507307461

Banerjee, T. (2001). The future of public space: Beyond invented streets and reinvented places. *Journal of the American Planning Association, 67*(1), 9–24. https://doi.org/10.1080/01944360108976352

Bentley, I. (2015). *Responsive environments: A manual for designers*. Architectural Press.

Biswas, B., Sultana, Z., Priovashini, C., Ahsan, M. N., & Mallick, B. (2021). The emergence of residential satisfaction studies in social research: A bibliometric analysis. *Habitat International, 109*, 102336. https://doi.org/10.1016/j.habitatint.2021.102336

Chokhachian, A., Santucci, D., & Auer, T. (2017). A human-centered approach to enhance urban resilience, implications and application to improve outdoor comfort in dense urban spaces. *Buildings, 7*, 113. https://doi.org/10.3390/buildings7040113

Clark, C., & Uzzell, D. (2006). The socio-environmental affordances of adolescents' environments. In C. Spencer & M. Blades (Eds.), *Children and their environments: Learning, using and designing spaces* (pp. 73–94). Cambridge University Press. https://doi.org/10.1017/CBO9780511521232.012

Daneshgarmoghaddam, G., & Eslampour, M. (2013). Study of the affordance theory based on Gibson's point of view and its effects on studies of human-built environment. *Armanshahr Architecture and Urban Development, Journal of Architecture, Urban Design and Urban Planning, 5*(9), 73–86.

Dannenberg, A. L., Frumkin, H., & Jackson, R. J. (2011). *Making healthy places*. Island Press.

Ding, W., & Lin, X. (2009). *Information architecture: The design and integration of information space*. Morgan & Claypool Publishers. https://doi.org/10.5822/978-1-61091-036-1

Dror, I. E., & Harnad, S. R. (2008). *Cognition distributed: How cognitive technology extends our minds*. John Benjamins Publishing Company. https://doi.org/10.1075/bct.16

Fayaz, E., Naderi, A., & Gharbi, M. (2019). Identity dynamics and identity construction consumption, a study in Golestan quarter of Sabzevar. *Sociological Review Journal, 26*(54), 221–247.

Fernandez-Portero, C., Alarcon, D., & Barrios Padura, A. (2017). Dwelling conditions and life satisfaction of older people through residential satisfaction. *Journal of Environmental Psychology, 49*, 1–7. https://doi.org/10.1016/j.jenvp.2016.11.003

Galster, G. C., & Hesser, G. W. (1981). Residential satisfaction. *Environment and Behavior, 13*(6), 735–758. https://doi.org/10.1177/0013916581136006

Gehl, J. (2011). *Life between buildings: Using public space*. Island Press.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton Mifflin.

Gordon Show, J. (1994). Transit, density, and residential satisfaction [Doctoral dissertation]. University of California. http://www.uctc.net/research/diss028.pdf

Grütter, J. K. (1987). *Aesthetik der Architektur: Grundlagen der Architektur-Wahrnehmung*. Kohlhammer.

Gupta, D., & Uma Maheswari, J. (2019). Affordance-based design method: A case study of university campus. *IOP Conference Series: Earth and Environmental Science, 323*(1), 012158. https://doi.org/10.1088/1755-1315/323/1/012158

Haft Shahr Aria Consulting Engineers. (2012). *Rehabilitation and renovation plan of Golestan old context (2nd revision)*. Sabzevar Municipality, Urban Rehabilitation and Renovation Organization. https://doi.org/10.1016/j.landurbplan.2014.10.001

Jabareen, Y. (2005). Culture and housing preferences in a developing city. *Environment and Behavior, 37*, 134–146. https://doi.org/10.1177/0013916504267640

Jusan, M. M. (2010). *Renovation for personalization: A development arm for sustainable housing*. UTM Press.

Kim, Y., Jeong, J., Kim, M. K., & Lee, S. W. (2008). Personal cognitive characteristics in affordance perception: The user activity case study in a building lobby. *Proceedings of the ASME Design Engineering Technical Conference, 3,* 909–921. https://doi.org/10.1115/DETC2008-50063

Lang, J. T. (1987). *Creating architectural theory: The role of the behavioral sciences in environmental design*. Van Nostrand Reinhold.

Lerup, L. (1972). Environmental and behavioral congruence as a measure of goodness in public space: The case of Stockholm. *Ekistics, 204*, 341–358.

Li, F., Yan, T., Liu, J., Lai, Y., Uthes, S., Lu, Y., & Long, Y. (2014). Research on social and humanistic needs in planning and construction of green buildings. *Sustainable Cities and Society, 12*, 102–109. https://doi.org/10.1016/j.scs.2014.03.003

Lynch, K. (1960). *The image of the city*. MIT Press.

Maier, J. R., & Fadel, G. M. (2003). Affordance-based methods for design. *Proceedings of the 15th International Conference on Design Theory and Methodology, 2003*, 785-794. https://doi.org/10.1115/detc2003/dtm-48673

Marans, R. W. (2015). Quality of urban life & environmental sustainability studies: Future linkage opportunities. *Habitat International, 45*, 47–52. https://doi.org/10.1016/j.habitatint.2014.06.019

Marcus, C. C., & Francis, C. (1990). *People places: Design guidelines for urban open space*. Van Nostrand Reinhold.

Maslow, A. H. (1971). *The farther reaches of human nature*. Harper.

Motalebi, Gh. (2002). Environmental psychology: The new knowledge-based discipline at architecture and urban design's service. *Honar-Ha-Ye-Ziba, 10*, 52–67.

Motalebi, Gh. (2006a). Recognition of form and functional ratio in architecture. *Honar-Ha-Ye-Ziba, 25*, 55–64.

Motalebi, Gh. (2006b). A human-based approach to form-making principles of urban spaces. *Honar-Ha-Ye-Ziba, 27*, 57–66.

Nickols, S. Y., Ralston, P. A., Anderson, C., Browne, L., Schroeder, G., Thomas, S., & Wild, P. (2009). The family and consumer sciences body of knowledge and the cultural kaleidoscope: Research opportunities and challenges. *Family and Consumer Sciences Research Journal, 37*(3), 266–83. https://doi.org/10.1177/1077727X08329561

Oldenburg, R. (1999). *The great good place: Cafes, coffee shops, community centers, beauty parlors, general stores, bars, hangouts, and how they get you through the day*. Paragon House.

Pakzad, J. (2010). *Theoretical basics & process of urban design* (4th ed.). Shahidi.

Potter, J. (2002). Residential environments: Choice, satisfaction and behavior. *Journal of Planning Literature, 17*(10), 2–25. https://doi.org/10.1177/088541202237339

Rishbeth, C. (2001). Ethnic minority groups and the design of public open space: An inclusive landscape? *Landscape Research, 26*(4), 351–66. https://doi.org/10.1080/01426390120090148

Rossi, P. H. (1955). *Why families move: A study in the social psychology of urban residential mobility*. Free Press.

Saffari Nia, M., Ammari, H., & Beheshti Moghaddam, E. (2013). *City psychology* (2nd ed.). Avaya Noor.

Salehi, E. (2008). *Environmental features of secure urban spaces*. Ministry of Housing and Urban Development Publication.

Temelová, J., & Dvořáková, N. (2012). Residential satisfaction of elderly in the city centre: The case of revitalizing neighbourhoods in Prague. *Cities, 29*(5), 310–17. https://doi.org/10.1016/j.cities.2011.11.015

Terzano, K. (2014). Residential satisfaction. In A. C. Michalos (Ed.), *Encyclopedia of quality of life and well-being research* (pp. 5526–27). Springer. https://doi.org/10.1007/978-94-007-0753-5_2491

Yung, E. H., Conejos, S., & Chan, E. H. (2016). Social needs of the elderly and active aging in public open spaces in urban renewal. *Cities, 52*, 114–22. https://doi.org/10.1016/j.cities.2015.11.022

Zavei, S. J., & Jusan, M. M. (2012). Exploring housing attributes selection based on Maslow's hierarchy of needs. *Procedia – Social and Behavioral Sciences, 42*, 311–19. https://doi.org/10.1016/j.sbspro.2012.04.195

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Article

Philosophical and methodological dimensions of grounded theory in architectural research: Content analysis of Turkish doctoral dissertations

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ABSTRACT

Grounded theory, originally developed in the social sciences as a systematic method for generating theory from data, has evolved into a flexible and philosophically diverse approach applied across multiple disciplines. Although its potential for theory-building aligns well with the needs of architectural research, its use within the field remains limited and often methodologically inconsistent. This study critically examines how grounded theory has been applied and adapted in architectural research by analyzing eleven doctoral dissertations completed in Türkiye between 2015 and 2024. Using content analysis, the dissertations were systematically evaluated across eight categories, including method, aim, data set, data collection techniques, data coding, data display, engaging with grounded theory literature and coding process transparency. The findings reveal three overarching themes that characterize the current use of grounded theory in Turkish architectural research: methodological adaptation and philosophical pluralism, knowledge construction through multi-layered data practices, and the need for analytical transparency. While the dissertations demonstrate the method's adaptability, they also highlight recurring issues such as terminological ambiguity, fragmented coding strategies, and insufficient engagement with core grounded theory processes including theoretical sampling, constant comparison, and theoretical saturation. By identifying methodological gaps and emerging tendencies, this study contributes to defining a clearer and more coherent framework for the future use of grounded theory in architecture.

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INTRODUCTION

Glaser & Strauss introduced grounded theory in their 1967 book, The Discovery of Grounded Theory. It was developed in the social sciences as a systematic research method for generating theory from data. Unlike traditional qualitative research methods that derive hypotheses from pre-existing theories, grounded theory proposes a clearly defined, three-stage process of data analysis, adopting an inductive approach to generate theory directly from empirical evidence. This method enables the construction of new theoretical insights without reliance on quantitative techniques (Charmaz, 2006). Over time, grounded theory has evolved into a more flexible framework, inspiring new methodological innovations in qualitative research.

Architecture's complex interplay of human experience, emotion, perception, cultural meaning, and daily life provides a fertile context for the application of grounded theory. The method's capacity to integrate empirical, experiential, and subjective data within a systematic analytical framework enables researchers to capture dimensions of architectural phenomena that are difficult to articulate through conventional approaches. Through its iterative and relational logic, grounded theory can reveal social, linguistic, experiential, conceptual, and symbolic patterns embedded in design processes—patterns that often remain implicit or overlooked in traditional research models. In this respect, grounded theory offers a valuable means of accessing and theorizing architecture's tacit knowledge, thereby deepening our understanding of the field's multifaceted nature.

Although grounded theory offers a strong potential for architectural research, its application within the discipline remains inconsistent. Adapting a method originally developed in the social sciences inevitably poses both conceptual and practical challenges. In architectural research, grounded theory is often employed without full awareness of its philosophical foundations or systematic coding procedures, resulting in partial implementations. Moreover, formal training in grounded theory is uncommon among architectural researchers, and only a few postgraduate programs provide comprehensive instruction in qualitative methodologies. This gap contributes to a broader uncertainty about how the method can be meaningfully adapted to design-based inquiries. Furthermore, there is a notable absence of studies in literature that explain or offer a coherent framework for applying grounded theory in architecture.

The primary aim of this study is to critically examine how grounded theory is understood and applied within architectural research, emphasizing both its methodological challenges and potential contributions. The study seeks to examine the philosophical and methodological foundations of the method to develop critical, reflective, and context-sensitive methodological awareness for architectural research. Grounded theory prioritizes theory generation over simply organizing data or offering superficial interpretations, making it especially suitable for doctoral-level research due to its methodological rigor and capacity for new conceptual insights. Accordingly, this study analyzes doctoral dissertations completed in Türkiye between 2015 and 2024 that explicitly use grounded theory.

The dissertations were systematically analyzed using eight criteria. These include method (the methodological framework used), aim (the study's intended outcome), data set (sources of data), data collection (techniques used to gather data), data coding (procedures for coding and analysis), data display (how results are presented), grounded theory literature (depth of theoretical engagement), and coding process transparency (clarity of methodological reporting). These categories form a framework for comparing the dissertations, allowing a systematic evaluation of their philosophical positioning, methodological rigor, and analytical clarity in applying grounded theory to architectural research.

The content analysis identifies three central themes shaping the use of grounded theory in architectural research: methodological adaptation and philosophical diversity, multi-layered data practices, and the need for analytical transparency. Together, these themes illuminate the underlying dynamics of how grounded theory is currently interpreted and operationalized within the discipline. They also enable the identification of recurring methodological tendencies, epistemological orientations, and patterns of application, revealing where researchers innovate, where they struggle, and where gaps persist.

The originality of this study lies in its focus on how grounded theory has been interpreted within architectural design research, rather than merely explaining what the method is. It is not simply a literature review, but a systematic and critical analysis of doctoral dissertations that employ grounded theory within the Turkish architectural context. By examining how the method is operationalized in practice, the study provides a comprehensive picture of current methodological tendencies, epistemological orientations, and emerging challenges. So, it contributes to defining a clearer and more reflective framework for the future use and development of grounded theory in architecture.

KEY CONCEPTS AND RECENT SHIFTS OF GROUNDED THEORY

Glaser & Strauss outlined clear procedures for data collection and analysis by providing practical methodological guidelines that connect data and theory (Charmaz, 2006). Grounded theory employs a cyclical, reflexive process that involves data collection, coding, memo writing, and theory development. Researchers move between these stages, refining concepts and categories as new insights emerge through constant comparison. This recursive structure ensures that theoretical outcomes stay closely grounded in empirical evidence and allows for continuous reinterpretation and conceptual growth.

As with all scientific studies, the study's objectives and research questions must be clearly defined before data collection. Grounded theory relies on qualitative data obtained through in-depth, semi-structured interviews, direct observations, documents, reports, media content, and other written materials. Data coding and analysis use systematic steps that transform raw data into theoretical concepts. The classical approach (Glaser & Strauss, 1967; Strauss & Corbin, 1990) uses open, axial, selective, and theoretical coding, emphasizing objectivity and the emergence of categories directly from data. In contrast, the constructivist approach (Charmaz, 2006) employs initial, focused, and theoretical coding, highlighting the researcher's interpretive role and the co-construction of meaning. Despite these methodological differences, each coding stage progressively refines data interpretation from descriptive categorization to conceptual integration ultimately culminating in the generation of theory.

The memo-writing stage sets grounded theory apart from other qualitative methods. Researchers document theoretical reflections with clear titles, dates, and continuous records, which helps connect codes and categories and identify conceptual gaps (Çelik & Ekşi, 2015). Theoretical sensitivity, shaped by prior experience, is vital in this process; it enhances the ability to recognize patterns and interpret data effectively (Strauss & Corbin, 1990). Another critical principle, theoretical saturation, is reached when additional data no longer yields new codes or insights, indicating that the analysis has captured the full conceptual scope of the phenomenon (Glaser & Strauss, 1967).

The method's strength lies in its capacity for theory building. Timonen et al. (2018) states that this method is typically used to understand a particular concept or conceptual framework thoroughly. Rather than merely compiling data, it enables the development of intermediate-level theories with conceptual depth. Grounded theory, specifically, provides a flexible yet rigorous framework for building substantive theories closely tied to participants' experiences and grounded in empirical evidence. These theories are inherently dynamic and context-sensitive, reflecting the involvement of multiple actors, interactions, and temporal dimensions. Table 1 highlights the key concepts of grounded theory with the definition and application in research phase to inform researchers.

Following the postmodern turn of the 1980s, creative fields such as media, art, film, and architecture adopted research perspectives that favored locality, fragmentation, contradiction, heterogeneity, and complexity over universality, generalization, rationality, and homogeneity (Clarke, 2003). In response, grounded theory evolved into two main strands -constructivist and situational grounded theory- each offering distinct approaches to addressing the needs of modern qualitative research.

Table 1. Key concepts of grounded theory.

Concept	Definition	Application in Research
Open / Initial Coding	The first phase of analysis involves line-by-line or segment-by-segment examination of data to identify significant ideas.	Generates initial codes representing participants' meanings and actions.
Axial / Focused Coding	A stage where codes are clustered and relationships among them are identified to form higher-level categories.	Clarifies central processes, causal relationships, and emerging patterns.
Selective / Theoretical Coding	The phase that integrates categories to form a coherent theoretical framework.	Leads to the identification of a core category that unites the analysis.
Memo Writing	The practice of documenting analytic reflections, theoretical notes, and conceptual linkages throughout the research process.	Promotes reflexivity and supports the construction of robust theoretical explanations.
Theoretical Sensitivity	The researcher's ability to perceive and interpret data meaningfully, shaped by experience and prior knowledge.	Increases analytical depth and ensures that emerging theories are contextually grounded.
Theoretical Saturation	The point at which additional data no longer generates new codes or insights.	Indicates the completeness and stability of developed categories.
Intermediate-Level Theory	A theory positioned between abstract grand theory and descriptive empirical findings.	Provides conceptual depth while remaining closely tied to the data.
Constant Comparison	A core analytic procedure involving the continuous comparison of data, codes, and categories.	Enables refinement of categories and discovery of relationships among concepts.

Charmaz (2016) proposed constructivist grounded theory, which encourages researchers to consider the ideological, social, and political contexts of the twenty-first century. Unique to this approach, data are viewed as open to multiple interpretations, and meaning is co-constructed through the interaction between researchers and participants. Constructivist grounded theory facilitates the connection between micro-level subjective experiences and macro-level social structures by emphasizing co-construction and context.

Clarke (2003, 2015) introduced situational grounded theory, which extends grounded theory by mapping social, discursive, and material relations. Situational maps visually illustrate the interconnections among actors and highlight the discursive, material, and spatial dimensions of research. Clarke's situational analysis responds to the need for analytical tools that depict positions and power relations, distinguishing itself from earlier grounded theory by expanding into post structural domains and emphasizing the complexity of relationality.

METHODOLOGICAL APPROACH AND SELECTION OF DISSERTATIONS

Grounded theory has evolved from its positivist origins toward more interpretive and context-sensitive orientations, accommodating a plurality of viewpoints and methodological nuances. These shifts have expanded the method's interpretive capacity and opened new possibilities for its application across diverse disciplines. Among these disciplines, architecture occupies a distinctive position. As a discipline that inherently integrates human experience, emotion, perception, and cultural meaning, architecture offers both significant opportunities and considerable challenges for adapting grounded theory.

Grounded theory is a well-established methodology in the social sciences. However, its application within design studies has not yet reached a comparable level of depth, partly because design remains a relatively young academic discipline when compared with fields such as physics, sociology, or philosophy (Friedman, 2003). Nevertheless, the use of grounded theory in architectural research has grown significantly since 2010. For instance, a comparison between the first (2002) and second (2013) editions of Groat and Wang's Architectural Research Methods shows a notable increase in pages devoted to grounded theory, reflecting its rising methodological value and relevance to architectural inquiry.

Doctoral dissertations serve as effective tools for tracing growth in new research fields, as they offer in-depth investigations in advanced degree programs. Compared to journal articles, dissertations often clarify methodological applications and research processes. Focusing dissertations using grounded theory reveals the shifting paradigms and innovative approaches underpinning the method's current and future trajectory. To understand the evolution of grounded theory in architecture, a systematic search of dissertations was conducted using ProQuest (a global collection of doctoral dissertations) and The Council of Higher Education (YÖK) (a database for dissertations in Turkiye).

In the ProQuest, a keyword search for "grounded theory" revealed that the highest number of dissertations appeared in the field of educational sciences, with lower counts in management, sociology, nursing, literature, psychology, and public health. By contrast, architecture had notably fewer dissertations using grounded theory. To refine the results for architecture specifically, the search combined "grounded theory" AND "architecture," resulting in approximately 500 dissertations, most completed after 2010. Most originated from institutions in the United States, followed by the United Kingdom, with Turkiye represented at a much lower rate.

A similar search strategy was applied to the Council of Higher Education (YÖK) database. Since multiple translations of the term are used in Turkish scholarship, the keywords *gömülü kuram, gömülü teori, temellendirilmiş kuram,* and *temellendirilmiş teori* were searched within titles, abstracts, and keywords. This search yielded 384 dissertations, again showing a marked increase in studies conducted after 2010 and reflecting a parallel disciplinary distribution to the international data. These results show a growing interest in grounded theory in both international and Turkish contexts since 2010. The parallel rise in international and national adoption underscores the method's emerging role and potential for further study in the discipline.

The search with the terms "architecture" and "grounded theory" identified 21 theses, a relatively low number compared to other social sciences. Of these, twelve were doctoral dissertations and nine were master's theses, all completed between 2015 and 2024. The majority (16 out of 21) were situated within architectural design, with only two in urban design and three in informatics in architectural design. To ensure a focused and comparable dataset, the present study includes only doctoral dissertations in architectural design as listed in Table 2.

Between 2015 and 2024, eleven dissertations in Turkiye explicitly employed grounded theory in architectural research, marking a methodological shift in Turkish architectural academia. Their chronological distribution reveals a steady increase, culminating in a distinct surge after 2022, which aligns with the global trend. Institutionally, Istanbul Technical University (3) and Yıldız Technical University (2) emerged as the initial centers of grounded theory adoption, followed by Dokuz Eylül University (2) and four other universities. Despite the diversity of supervisory backgrounds, these dissertations originated from only seven universi-

Table 2. The list of dissertations.

	Name	Year	Writer	Advisor	School
D1	A Transdiscursive Enquiry on Urban Identity	2015	Avşar Karababa	Prof. Dr. Semra Aydınlı, Doç. Dr. Lena Hopsch	Istanbul Technical University
D2	Questioning Architectural Envelope - Context Relationship in Contemporary Architecture	2016	Hande Düzgün Bekdaş	Prof. Dr. Çiğdem Polatoğlu	Yıldız Technical University
D3	Grey Matter: Perception of Semi-Open/ Open Semi-Public/Semi-Private Spaces in The Housing Areas by Young Adults	2016	Sedef Özçelik Güney	Prof. Dr. Yurdanur Dülgeroğlu	Istanbul Technical University
D4	"Active Studio" Experiences in Architectural Design Education	2017	Bengi Yurtsever	Prof. Dr. Çiğdem Polatoğlu	Yıldız Technical University
D5	Employing Grids: A Discursive Account of Spatial and Performative Skills	2022	Hatice Cansu Cürgen Gürpınar	Prof. Dr. Hüseyin Kahvecioğlu	Istanbul Technical University
D6	Space Plasticity in Architecture	2022	Zeynep Sadıklar	Prof. Dr.Asu Beşgen	Karadeniz Technical University
D7	A Conceptualization for Research-Based Architecture Between Theory and Practice: An Atlas for Architectural Research in Türkiye	2022	Zeynep Dündar	Prof. Dr. Gökçeçiçek Savaşır	Dokuz Eylül University
D8	Analysis of Informal Environments in Architectural Education in Türkiye	2023	Nurten Özdemir Gökmen	Prof. Dr. Hikmet Gökmen	Dokuz Eylül University
D9	Competitions In Architecture-Urban Design Knowledge Seeking	2023	Doğan Ümit Yücel	Prof. Dr. Aysu Akalın	Gazi University
D10	Image After Representation: Cartographic Paradigm in Architecture	2024	Doruk Can Özçifçi	Prof. Dr. Fatma Zeynep Aygen	Mimar Sinan University
D11	Space and Place in Dr. M. Mansour Falamaki's Architectural Thinking Through Hafız's Poetry and Merleau-Ponty's Phenomenology	2024	Farnaz Kimya	Prof. Dr. F. Cânâ Bilsel	Middle East Technical University

ties. The topics addressed in these dissertations range from urban identity to representation and phenomenology, demonstrating the method's adaptability across different scales and epistemological positions.

This study employs content analysis to explore the methodological and philosophical dimensions of grounded theory in architectural research. Through systematic coding and categorization, content analysis identifies patterns, frequencies, word relationships, and communication structures (Pope et al., 2006; Gbrich, 2007). Once coded, the raw data is processed, summarized, and interpreted within predefined categories. The process unfolds in four main stages: identifying categories, processing data, describing findings, and interpreting results. Ultimately, content analysis not only reveals prevailing trends within a given field but also informs future research (Miles & Huberman, 1994).

Rather than merely reviewing methodological descriptions, the analysis aims to understand how grounded theory has been interpreted, adapted, and operationalized within the architectural discipline. The analytical categories defined for context analysis are systematically matched with the content of each dissertation, allowing for the identification of recurring patterns, methodological tendencies, and philosophical orientations that define the themes in the next section.

PHILOSOPHICAL AND METHODOLOGICAL DIMENSIONS OF GROUNDED THEORY IN ARCHITECTURAL RESEARCH

Findings of Content Analysis

The dissertations were examined through eight analytical categories: method, concerning the overall research approach employed; aim, referring to the specific research goal, whether conceptual, theoretical, or empirical; data set, addressing the type and origin of collected data and specifying whether the sources are human or non-human; data collection, describing the tools and procedures used to gather data; data coding, which includes techniques for turning raw data into conceptual categories; data display, referring to the ways findings are visually or textually presented; reference to grounded theory literature, indicating the degree to which the methodology is supported by established scholarship; and description of the coding process, showing the transparency and detail provided regarding data analysis steps (Table 3).

The first category addresses the philosophical foundations of grounded theory. Accordingly, D4, D7, and D8 apply constructivist grounded theory, while D1, D2, and D3 adopt a mixed method that integrates grounded theory with at least one additional method, such as discourse analysis or case study. The remaining dissertations do not specify a particular philosophical stance, reflecting a general tendency to employ grounded theory in a traditional manner.

The aim of the study examines how each dissertation defines its central conceptual orientation. In general, the dissertations commonly aim to construct a conceptual or theoretical framework by identifying a specific phenomenon, situation, concept, or individual as the core research problem. The primary motivation for employing grounded theory is its capacity to uncover hidden or tacit knowledge embedded within these contexts. For instance, D1, D2, D3, D5, D6, D7, D9, and D10 aim to generate new conceptual insights and reveal the underlying relationships in particular architectural phenomena. In contrast, D4, D9, and D11 focus on exposing implicit dimensions of knowledge within specific situations or individual experiences.

Data source examines the types and range of data used. The dissertations exhibit a diverse range of data forms and materials. D2, D3, and D4 primarily focus on human actors (such as interviewees, participants, or users), while D1, D5, D6, D9, D10, and D11 focus on non-human actors (including artifacts, documents, or environments). Meanwhile, D7 and D8 analyze both human and non-human actors, taking a hybrid approach. Within the non-human category, data sources include a notable range of written materials including journals, online art and design platforms, books, manuals, lecture notes, archives, theses, blogs, jury reports, competition briefs, regulations and visual materials such as architectural drawings, maps, photographs, images, and other representational materials.

Data collection method focuses on how data are gathered to construct and refine theoretical insights. The literature on grounded theory emphasizes the importance of in-depth interviews as a primary method for collecting data. A semi-structured interview format is implemented in D1, D3, D4, D7, D8, and D11. The studies also incorporate complementary techniques such as observation, case studies, and surveys, enabling a more comprehensive understanding of the context. Furthermore, each dissertation includes a systematic review of the existing literature related to its research topic, both to frame the study context and to inform the coding and theoretical processes.

Data coding examines how data are analyzed and transformed into conceptual categories through systematic coding procedure, distinguishing grounded theory from other qualitative approaches. Although D1, D2, D3, and D10 reference the stages of grounded theory coding in the literature, they do not provide practical illustrations of these procedures. Variations in terminology are inherent to the method; for instance, seven dissertations explicitly reference the three-step coding process. Those using terms such as open, axial, and selective coding adhere to the classical grounded theory model, while those referring to initial, focused, and theoretical coding align more closely with a constructivist approach. Additionally, another notable observation concerns the use of manual versus digital coding techniques. While D9 and D11 employ digital tools such as MAXQDA and ATLAS.ti, the remaining dissertations rely on manual coding, utilizing printed transcripts, notes, or spreadsheet-based matrices.

D5, D6, D7, D8, D9 and D11 transparently present their coding processes, either within the main text or in the appendices, often using tabular representations that make the analytical procedure traceable and replicable for other researchers. However, the others do not fully disclose their coding procedures, providing only general descriptions without concrete examples or visualizations.

Data display focuses on how the analyzed data are visually represented and conceptually organized. In all studies, tables are used to illustrate how raw data is transformed into initial or focused codes. Network diagrams, concept maps, and atlas visualizations, typically developed during the theoretical coding stage, serve as creative tools that depict the relationships among codes, categories, and emerging concepts. D6, D7, D8, D10, and D11 provide particularly strong examples of diverse and innovative data display strategies, demonstrating how visual thinking enhances methodological transparency and theoretical synthesis.

The analysis reveals that each dissertation employs a distinct approach, highlighting the diverse ways in which grounded theory is applied within architecture. D1, recognized as the earliest example of grounded theory in this field, treats the method not conventionally but rather as a complementary tool. D2 employs a coding process that is not strictly tied to grounded theory; instead, it proposes an experimental conceptualization through a mixed-methodology approach, integrating discourse analysis and grounded theory. D3 stands out for its wide range of data collection tools, cyclical and iterative research design, and extensive use of quantitative data. In D4, assumptions are formulated before each cycle and updated based on emerging data, and the introduction includes a glossary of key terms related to the method. D5 diverges from the standard approach by applying a unique interpretation during the coding process.

D6 utilizes tables to illustrate the coding procedure transparently, suggesting a foundational model that is adaptable to various other studies. D7 constructs its own body of knowledge via grounded theory, culminating in a layered,

Table 3. Content analysis of the dissertations.

	Method	Aim	Data Source	Data Collection	Data Coding	Data Display	Literature Review	Coding Process
D1	Mixed method / grounded theory as a tool	Conceptual study	Non-human actors (Urban areas: Asmalımescit, Levent-Kağıthane, Kuzguncuk)	Literature review, observation, in-depth interviews	No Reference to grounded theory's coding stages	Narratives and diagrams	-	-
D2	Mixed method / grounded theory + discourse analysis	Conceptual study	Human actors (discourses of architects engaged in media and literature)	Content analysis on manifestos, books and articles	Thematic coding / no reference to grounded theory's coding stages	Tables, concept maps and conceptual network diagrams	-	-
D3	Mixed method / grounded theory + quantitative strategies	Conceptual study	Human actors (people living in Maslak/Beşiktaş/ Beyoğlu/Şişli on the metro line)	Observation, survey, in-depth interview, case study	A layered and relational coding process / no reference to grounded theory's coding stages	Tables	-	-
D4	Constructivist grounded theory	Conceptual study	Human actors (participants of architectural design studio)	Survey, in-depth interview	Initial coding, focused coding, theoretical coding	Tables	+	-
D5	Grounded theory	Conceptual study	Non-human actors (journals, online art and design platforms, books, design and construction manuals, lecture notes, and archives of museums and institutions)	Content analysis on data set	Open coding, focused coding, and theoretical coding	Tables	+	+
D6	Grounded theory	Theoretical framework	Non-human actors (Dictionaries, encyclopedias, programs, manifestos)	Literature review, survey	Open coding, axial coding, and selective coding	Concept maps and conceptual network diagrams	+	+
D7	Constructivist grounded theory	Conceptual study	Human + nonhuman actors (architectural firms, associations, NGOs, public institutions, municipalities, and academia, design research literature)	Literature review, in-depth interview	Initial coding, focused coding, theoretical coding	Diagrams and atlas	+	+
D8	Constructivist grounded theory	Conceptual study	Human + nonhuman actors (literature on informal learning methods in architecture, articles, theses, blogs and architects)	Literature review, in-depth interview	Initial coding, focused coding, theoretical coding	Diagrams and tables	+	+
D9	Grounded theory	Conceptual study	Non-human actors (Akhisar Municipality architectural and urban design idea competition question-and-answer sessions, jury reports, and participants' proposals)	Content analysis on data set, literature review	MAXQDA, initial coding,axial coding, and focused coding	Tables, word cloud	+	+
D10	Grounded theory	Conceptual study	Non-human actors (images: drawins, maps, manuscripts,pictures)	Content analysis on data set	No reference to grounded theory's coding stages	Diagrams	+	-
D11	Grounded theory	Conceptual study	Human actors (books and documents)	Content analysis on data set, in-depth interview	Atlas.ti, Open Coding, axial coding, selective coding	Tables and diagrams	+	+

open-ended, and interpretable result presented in an atlas-style format. D8 provides detailed tables of its initial, focused, and theoretical coding stages in both the main text and the appendix, offering readers a clear view of the methodology. D9 aligns grounded theory with a phenomenological and hermeneutic approach, utilizing MAXQDA software to analyze a specific case and uncover its tacit knowledge, rather than relying on a large dataset. Finally, D10 relies on images as its primary data source, while D11 focuses on a single individual's discourse and outputs, setting both apart from the other studies.

Discussions for Adopting Grounded Theory in Architectural Research

The content analysis reveals that the use of grounded theory in architectural research is shaped by three overarching themes: methodological adaptation and philosophical pluralism, knowledge construction through multi-layered data practices, and analytical transparency. Building on these insights, the following discussion examines the implications of these themes for the future adoption of grounded theory in architecture, highlighting both the opportunities it offers, and the methodological refinements required to strengthen its application.

Figure 1 illustrates the overall process of applying grounded theory in architectural research. The diagram not only visualizes the core components of grounded theory but also aligns them with architecture-specific research strategies identified through the content analysis. In doing so, it maps each stage of the grounded theory process onto the three key themes revealed in the section showing how the method's foundational concepts intersect with architecturally grounded research practices.

Methodological adaptation and philosophical pluralism: Grounded theory encompasses various philosophical perspectives, each shaped by distinct epistemological assumptions and analytical strategies. This diversity enriches the field but can confuse novice researchers, who may struggle to distinguish between different interpretations and applications. The findings underscore the importance of establishing clear methodological guidelines and consistent terminology to ensure research rigor and transparency. Researchers must understand the philosophies, tactics, and strategies of each grounded theory approach and reference them explicitly in their studies.

The analysis shows that several dissertations integrate grounded theory with complementary methods such as discourse analysis, case study, or content analysis, aiming

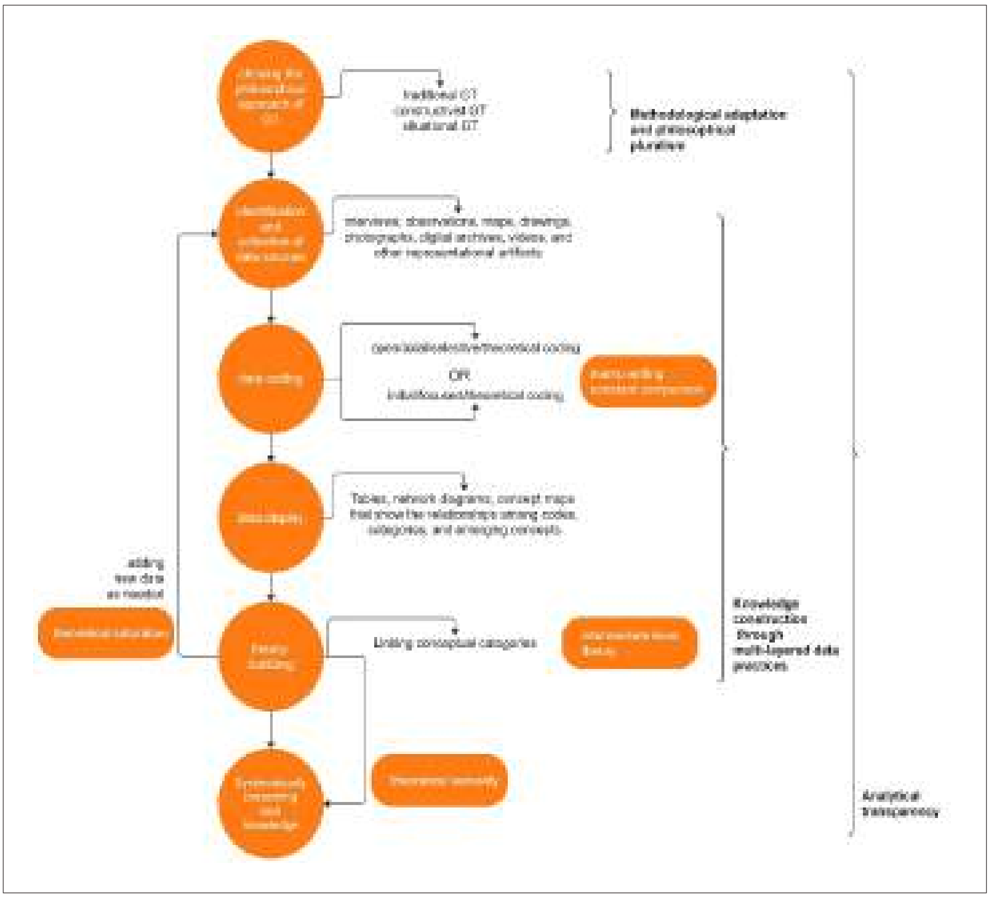

Figure 1. The process of grounded theory in architecture.

to build multi-layered research frameworks. These hybrid designs demonstrate the method's flexibility and its capacity to generate multidimensional insights. However, such integrations require a clearly articulated research rationale, supported by comprehensive literature discussions and visual diagrams that explain how methods are combined to ensure methodological coherence.

Content analysis reveals that many dissertations fail to adequately treat grounded theory as a primary research methodology. Instead, it is frequently positioned as a secondary or supportive analytical tool, applied superficially rather than systematically. This tendency suggests that grounded theory's full potential in architectural research, particularly its capacity for theory building and epistemological innovation remains underutilized. Researchers should explicitly justify why grounded theory is chosen over alternative research methods, specify which grounded theory approach they follow, and define key methodological terms. Articulating how these decisions align with the study's aims not only clarifies the internal logic of the research but also contributes to cultivating a more robust and reflective methodological culture within architectural research.

Suddaby (2006) emphasizes that a robust grounded theory study requires substantial experience, deep subject-matter knowledge, and strong analytical skills. To overcome these methodological and philosophical challenges, researchers must work with supervisors who are knowledgeable in qualitative methodologies. They can also enroll in specialized courses and cultivate critical reading practices to understand the philosophical and procedural nuances of different grounded theory approaches. In addition, participating in research groups, peer-discussion networks, and academic workshops or conferences helps researchers refine their methodological awareness (McCallin, 2003). This allows them to navigate the complexities of applying grounded theory in interdisciplinary contexts.

Knowledge construction through multi-layered data practices: While grounded theory traditionally relies on human participants as primary data sources, architectural research expands the notion of data far beyond human. These sources include observations, maps, drawings, photographs, digital archives, videos, and other representational artifacts (Lianto, 2018). This diversity reflects the multimodal nature of architectural inquiry, distinguishing the field from many social science applications of grounded theory. Such non-human data sources provide access to tacit, embodied, and spatial forms of knowledge that are central to architectural design.

Parallel to diversity of data sources, the dissertations demonstrate wide-ranging data collection strategies. Diversity data collection tools can significantly enhance findings (Birks & Mills, 2015). In addition to semi-structured interviews researchers employ observations, design studio documentation, photographic surveys, and written materials or reflective notes. This diversity not only broadens the empirical base of each study but also enhances the interpretive depth of grounded theory analysis.

A recurring misconception is that grounded theory discourages engagement with previous works (Suddaby, 2006). In contrast, the dissertations show that literature can and often should be treated as a data set, coded in parallel with empirical materials. When used systematically, literature coding strengthens methodological coherence by grounding new insights into established knowledge while still allowing new conceptual patterns to emerge inductively.

The coding process is the most fundamental stage that distinguishes grounded theory from other methods. Although architectural research benefits from a wide range of data sources, collection techniques, and representational formats which offer considerable creative potential, this diversity can also lead to noticeable inconsistencies and methodological fragmentation during coding. Yet the multi-stage coding structure that lies at the core of grounded theory such as open/axial/selective coding or initial/focused/theoretical coding, constitutes a critical component that shapes the method's epistemological stance, analytical depth, and overall theoretical coherence. Thus, the coding stages represent the most clearly defined and least open-to-interpretation component of the method. The analysis shows that many dissertations describe coding only in general terms, without providing concrete examples, tables, or visualizations. Such omissions obscure what the most characteristic and creative phase of grounded theory is arguably, weakening the robustness of the resulting theoretical frameworks.

Depending on the volume and complexity of the data, coding in grounded theory studies may be conducted manually or with the assistance of software. Manual coding enables a closer and more interpretive engagement with the data, enhancing sensitivity to contextual and semantic nuances. However, managing large data sets can pose significant challenges, making qualitative data analysis software advantageous for organizing and systematizing the coding process. In the dissertations examined, critical reflections on how the chosen method affects the reliability, depth, or the researcher's role in the analysis are largely absent. Yet excessive reliance on such tools may weaken the researcher's interpretive closeness to the data and limit the degree of interaction required by grounded theory. For this reason, it is crucial that researchers actively direct and oversee the coding process rather than delegating it entirely to the software.

Unlike other research methods, grounded theory does not focus on testing an existing theory or simply counting words (Suddaby, 2006). As Morse (2016) emphasizes, grounded theory is not governed by rigid procedural formulas; instead, it prioritizes an iterative, process-oriented engagement with data. Importantly, grounded theory requires researchers to recognize and articulate the emergent relationships within their data not merely as descriptive outcomes but as the foundations of new conceptual understanding This relational understanding of data is particularly relevant for architectural research, where complexity, ambiguity, and layered meanings are inherent to the subject matter.

The analysis of dissertations reveals, however, that grounded theory's strongest contribution, its capacity for theory building remains underutilized within architectural research. Many dissertations struggle to translate their rich data into fully developed theoretical frameworks. This difficulty is partly tied to insufficient engagement with the core analytical mechanisms of grounded theory, such as theoretical sampling, constant comparison, and theoretical saturation. These procedures require ongoing iteration, critical reflexivity, and conceptual precision; yet in several dissertations, they are mentioned only briefly or applied superficially, limiting the depth and robustness of the resulting theory. Detailed explanations of how theoretical sampling is conducted, how comparative strategies inform concept refinement, and how saturation criteria are established would significantly enhance methodological clarity.

One of the central challenges for novice grounded theory researchers is the dual responsibility of being both the data collector and the data analyst (McCallin, 2003). This dual role requires a delicate balance between objectivity and reflexivity. Researchers must simultaneously engage with the field through interviews, observations, and other techniques while continuously analyzing the data in real time. This iterative interaction demands sustained analytical awareness, as insights emerging during data collection often reshape subsequent analytical directions.

Grounded theory explicitly encourages the incorporation of personal data such as field notes, reflective memos, and spontaneous observations. These materials enrich the analytical process by capturing subtle interactions, contextual nuances, and experiential impressions that may not be fully visible in formal data sources. However, this also means that the researcher's interpretive lens shaped by their assumptions, experiences, and theoretical sensitivities, inevitably influences the development of emerging concepts. In this sense, grounded theory positions the researcher not as a neutral observer but as an active participant in the knowledge-production process. Strengthening reflexivity is therefore a critical requirement for grounded theory in architecture where subjective interpretations and experiential judgments are integral to both the research process and the phenomena.

Analytical transparency: Analytical transparency is a fundamental requirement for ensuring the reliability of grounded theory studies. One of the major obstacles to transparency is conceptual inconsistency and terminological ambiguity. Researchers must clearly articulate their methodological stance and the terminology they employ. Yet, in the dissertations examined, terminology is often mixed across different grounded theory traditions. This pattern supports the broader finding that, despite its long history, many researchers possess only a partial understanding of the philosophical and procedural foundations of grounded theory (Fernandez, 2004). Although consulting foundational sources can enhance conceptual clarity, individual interpretation may still introduce ambiguity an issue also observed in several dissertations analyzed.

At this point, including a glossary of key grounded theory terms within dissertations can significantly improve terminological clarity. As exemplified in D4, providing a brief glossary of core concepts strengthens the researcher's methodological positioning and enables readers to follow the chosen approach more accurately and consistently. This practice is particularly beneficial in studies where terms from different grounded theory traditions are used concurrently, offering an effective way to maintain conceptual coherence.

Moreover, the term grounded theory and its associated concepts appear in Turkish academic literature through several parallel translations, *gömülü kuram, gömülü teori, temellendirilmiş kuram, and temellendirilmiş teori*. Because these variants are used inconsistently across publications, researchers conducting literature search in Turkish risk overlooking relevant studies if they rely on only a single version of the term. To prevent such omissions and to increase accessibility, it is essential for researchers to be aware of these different translations. Furthermore, including multiple Turkish equivalents as keywords or referencing them explicitly within the text can significantly improve searchability and visibility, ensuring that future studies are more easily discoverable within the national research landscape.

Consistency is also an essential component of analytical transparency. In grounded theory studies, researchers should clearly describe the types of data they use, the procedures through which codes and categories are generated at each stage, and the evidence demonstrating that these codes genuinely emerge from the data rather than from preconceived assumptions. However, in practice, presenting the full coding process particularly the first two stages of coding can be challenging in articles or dissertations, especially when the dataset is extensive. In such cases, it is advisable to include selected examples of the coding procedure within the main text to illustrate the analytical logic, while providing the complete coding scheme in the appendices or through supplementary online materials such as cloud-based repositories. Of course, the extent to which these materials can be shared depends on issues of confidentiality and the researcher's ability to make their data publicly accessible. Ensuring this balance between transparency and ethical responsibility is crucial for strengthening methodological rigor in grounded theory research.

Equally important is the explicit sharing of the researcher's experiences, challenges, and decision-making processes encountered during the application of the method. Providing reflexive accounts of methodological difficulties such as managing simultaneous data collection and analysis, navigating ambiguous categories, or determining saturation enhances the credibility of the study and offers valuable guidance for future researchers.

CONCLUSION

This study comprehensively examines how Turkish architectural researchers adopt and interpret grounded theory, systematically analyzing doctoral dissertations. Grounded theory in the Turkish architectural research context is not yet an established method, but rather an emerging and evolving practice. The terminological inconsistencies, limited transparency in coding procedures, and ambiguity regarding the link between method and philosophical stance reflect the fact that the method is still relatively new within this disciplinary and national setting.

By contrast, in countries where grounded theory has a longer and more institutionalized history such as the United States, the United Kingdom, and Australia more systematic methodological training, well-developed qualitative research communities, and stronger traditions of theory building have enabled researchers to achieve higher levels of methodological consistency and analytical transparency. However, this disparity should not be viewed solely as a deficit. It also represents a productive space for growth, experimentation, and innovation within the Turkish context. The relatively recent adoption of grounded theory in Turkish architectural research allows for diverse epistemological interpretations and opens room for creative, interdisciplinary applications.

Integrating grounded theory into doctoral programs creates an environment that strengthens methodological competence while fostering scholarly dialogue. This holistic approach equips researchers with the critical, reflexive, and theoretically informed perspectives necessary to engage with grounded theory in a rigorous and meaningful way. Moreover, researchers' honest accounts of the challenges they encounter, the adjustments they make, and the experiences they gain throughout the process enhance collective learning, thereby improving methodological transparency and reproducibility within the field of architecture. In this way, supportive academic environments that prioritize experience-sharing and continuous methodological refinement become essential for conducting robust grounded theory research.

Ultimately, the purpose of methodological inquiry in architecture should not be to reproduce a fixed model or to pursue methodological perfection as an end. The goal is not to turn grounded theory or any method into an object of methodological fetishism, but rather to use it as a means of critical reflection and conceptual discovery. What matters is cultivating an awareness of why and how a method is employed, and what kinds of knowledge it allows us to produce or obscure. In this sense, grounded theory should be understood not as a prescriptive framework but as a dynamic interpretive lens that invites architectural researchers to question their assumptions, refine their analytical strategies, and contribute to a more pluralistic and reflexive research culture within the discipline.

The review reveals a positive, cumulative progression, as each study builds upon the insights of its predecessors. This trajectory suggests a promising potential for qualitative advancement in Turkish architectural research. Consequently, it becomes an academic responsibility to develop a thorough understanding of grounded theory and to conduct flexible, creative studies that remain aligned with its underlying philosophy. To foster this growth, it is essential to broaden the scope of discussion, strengthen collaborative communication platforms among researchers, adopt a patient yet critical stance, and refine feedback mechanisms. In this regard, the present study aims to contribute meaningfully to the field and catalyze further research and methodological innovation in architectural scholarships.

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REFERENCES

Birks, M. & Mills, J. (2015). *Grounded theory: A practical guide*. Sage.

Çelik, H. & Ekşi, H. (2015). *Nitel desenler: Gömülü teori*. EDAM.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. SAGE.

Charmaz, K. (2016). Shifting the grounds: constructivist grounded theory methods. J. M. Morse, P. N. Stern, J. Corbin, B. Bowers, K. Charmaz & AE. Clarke (Eds.). *Developing grounded theory: the second generation* (pp. 127–155). Routledge.

Clarke, A.E. (2003). Situational analyses: grounded theory mapping after the postmodern turn. *Symbolic In-*

teraction, 26(4), 553–576. https://doi.org/10.1525/si.2003.26.4.553

Clarke, A.E. (2015). From grounded theory to situational analysis: What's new? Why? How? A. E. Clarke, R. Washburn & C. Friese (Eds.). *Situational analysis in practice: mapping research with grounded theory* (pp. 84–118). Left Coast Press.

Cürgen, G. C. (2022). *Employing grids: a discursive account of spatial and performative skills [Unpublished doctoral dissertation]*. İstanbul Technical University.

Dündar, Z. (2022). *A conceptualization for research-based architecture between theory and practice: An atlas for architectural research in Turkey [Unpublished doctoral dissertation]*. Dokuz Eylül University.

Düzgün, H. (2016). *Questioning architectural envelope - context relationship in contemporary architecture [Unpublished doctoral dissertation]*. Yıldız Technical University. https://doi.org/10.5505/megaron.2016.53315

Fernandez, W. (2004). The grounded theory method and case study data in is research: issues and design. *Information Systems Foundations Workshop: Constructing and Criticising, 1*(22), 43–59.

Friedman, K. (2003). Theory construction in design research: Criteria, approaches, and methods. *Design Studies, 24*(6), 507–522. https://doi.org/10.1016/S0142-694X(03)00039-5

Gbrich, C. (2007). *Qualitative data analysis: An introduction*. Sage.

Glaser, B. G. & Strauss, A. (1967*). The discovery of grounded theory: Strategies for qualitative research*. Aldine Publishing Company. https://doi.org/10.1097/00006199-196807000-00014

Groat, L. N. & Wang, D. (2013). *Architectural research methods*. John Wiley & Sons.

Karababa, A. (2015). *A transdiscursive enquiry on urban identity [Unpublished doctoral dissertation]*. İstanbul Technical University.

Kimya, F. (2024). *Space and place in Dr. M. Mansour Falamaki's architectural thinking through Hafız's poetry and Merleau-Ponty's phenomenology [Unpublished doctoral dissertation]*. Middle East Technical University.

Lianto, F. (2018, November 27–28). *Grounded theory methodology in architectural research.* ICCOMSET 2018, Tasikmalaya, Indonesia.

Mccallin, A. M. (2003). Designing a grounded theory study: some practicalities. *Nursing in Critical Care, 8*(5), 203–208. https://doi.org/10.1046/j.1362-1017.2003.00033.x

Miles, M. B. & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage.

Morse, J. M. (2016). Tussles, tensions, and resolutions. J. M. Morse, P. N. Stern, J. Corbin, B. Bowers, K. Charmaz and A. E. Clarke (Eds.). *Developing grounded theory: the second generation*. Routledge. https://doi.org/10.4324/9781315430577

Özçelik, G. S. (2016). *Grey matter: perception of semi-open/open semi-public/semi-private spaces in the housing areas by young adults [Unpublished doctoral dissertation]*. İstanbul Technical University.

Özçifçi, D. C. (2024). *Image after representation: cartographic paradigm in architecture [Unpublished doctoral dissertation]*. Mimar Sinan University.

Özdemir, G. N. (2023). *Analysis of informal environments in architectural education in Türkiye [Unpublished doctoral dissertation]*. Dokuz Eylül University.

Pope, C., Ziebland, S. & Mays. N. (2006). Analysing qualitative data. C. Pope & N. Mays (Eds.). *Qualitative research in health care (*3rd ed, pp. 63–81). Blackwell Publishing. https://doi.org/10.1002/9780470750841.ch7

Sadıklar, Z. (2022). *Space plasticity in architecture [Unpublished doctoral dissertation]*. Karadeniz Technical University.

Strauss, A. & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques.* Sage.

Suddaby, R. (2006). From the editors: what grounded theory is not. *Academy of Management Journal, 49*(4), 633–642. https://doi.org/10.5465/amj.2006.22083020

Timonen, V., Foley, G. & Conlon, C. (2018). Challenges when using grounded theory: A pragmatic introduction to doing gt research. *International Journal of Qualitative Methods, 17*(1), 1–10. https://doi.org/10.1177/1609406918758086

Yücel, D. Ü. (2023). *Competitions in architecture-urban design knowledge seeking [Unpublished doctoral dissertation]*. Gazi University.

Yurtsever, B. (2017). *"Active Studio" experiences in architectural design education [Unpublished doctoral dissertation].* Yıldız Technical University.

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Article

Optimizing housing floor layout for cool terraces: A comparative analysis using constrained problem formulation

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ABSTRACT

As urban densification increases, thermal stress in cities becomes a problem. The integration of climate-sensitive strategies into housing design has become a necessity. As a strategy, design of terraces, as thermally configured outdoor spaces can reduce solar radiation gain. Parametric modeling, one of the computational approaches, provides significant contributions to optimizing the integration of environmental analysis into the terrace design. Although some related studies have focused on optimizing urban mass organizations for thermal comfort and solar performance, none of them have addressed spatial organization of terraces in residential buildings. This study presents a computational housing model to investigate terrace allocation with respect to solar gain, including circulation and residential units. The interstitial spaces are considered "cool terraces", and the objective is to minimize the solar radiation on terraces by optimizing the location and size of the residential units using a genetic algorithm via the Galapagos plug-in, radial basis function optimization (RBFOpt), and covariance matrix adaptation with evolution strategy (CMA-ES) using Opossum plug-in. To provide feasible spatial organization, constraints are determined using the near feasibility threshold with the Optimus plug-in. Results showed that only CMA-ES discovered feasible spatial organization while improving the solar performance of cool terraces. When compared to the benchmark design scenarios, the optimized alternative performed 11–26% improvement in solar radiation minimization. The study discusses the challenges in identifying well-performing cool terrace solutions, the complexity of the problem, and the applicability of optimization algorithms.

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INTRODUCTION

Background

Urbanization is one of the major anthropogenic effects in land use and has a significant effect on the development of the urban heat island (UHI) phenomenon (Singh, et al., 2017). As urban areas expand and environmental conditions change, the demand for accommodating growing populations necessitates urgent attention. Urbanization is therefore one of the driving forces of housing demand based on increasing requirements for sustainable living alternatives (Bangura & Lee, 2023). The changing needs, demands for housing, and climate challenges result in a gradual shift from conventional aesthetic understanding and functional concerns to performance-based design approaches in residential buildings (Li et al., 2020). When building performance-based design decisions arise, especially in relation to environmental concerns, traditional architectural design concepts like 'form follows function' can no longer present efficient solutions to the relationship between performance and form (Wang et al., 2025). Thus, it has necessitated the development of new computational frameworks that incorporate form generation and performance evaluation into a design process (Wang & Chai, 2025). In this context, parametric design is widely used as a design investigation approach to ensure sustainable alternatives during the conceptual design phase (Ajtayné Károlyfi & Szép, 2023). Hence, computational design tools and performance optimization methods have made it possible to include various environmental analysis criteria in the early design phase.

Cool terraces can reduce urban heat islands and building energy consumption, while their effectiveness is affected by local climatic conditions and building types (Zhao & Zhang, 2023). Therefore, optimizing solar radiation analysis, which greatly affects the energy performance and spatial comfort of buildings, is an important requirement to increase energy efficiency, especially in cool terraced housing designs. Nevertheless, allocating living spaces with respect to the performance aspects is a complex task as it requires investigating multiple design parameters. In this context, the parametric design approach can be an effective solution to integrate solar radiation analysis, as well as computational optimization methods, to identify well-performing cool terrace alternatives during the design process.

This study presents a comparative analysis for optimizing the performance of cool terraces using parametric modeling, building performance evaluation, and optimization algorithms in the conceptual design phase. The parametric model consists of the layout and dimensioning of six masses placed on one floor of a cool terraced residential building. The performance evaluation integrates solar radiation analysis into the developed parametric model for evaluating the performance of cool terraces. The performance-based parametric design model is integrated to the optimization algorithms, namely radial basis function optimization (RBFOpt) (Costa and Nannicini, 2018), and covariance matrix adaptation with evolution strategy (CMA-ES) (Hansen & Ostermeier, 2001) using Opossum plug-in (Bleicher, 2019), and genetic algorithm (GA) using Galapagos plug-in (Rutten, 2010) to evaluate the effectiveness and capability of different optimization methods to cope with such complex design problems. Near-feasibility threshold (NFT) is also considered to handle the constraint functions using the Optimus plug-in to identify feasible design alternatives that meet the allocation and the minimum spatial area constraints. Finally, optimization results are compared with the performance of benchmark scenarios to identify the efficacy of the proposed method.

Problem Statement

Rapid urbanization, population growth, and climatic problems have revealed a need for sustainable and climate-compatible housing designs. Cool terraces used in residential buildings significantly affect environmental performance and spatial quality. However, the design of cool terraces is complex due to the building form, spatial organization, and evaluation of the performance. Existing approaches mostly focus on utilizing conventional methods that do not support design investigation using optimization algorithms during the early design phase. Therefore, a computational design method that evaluates spatial, functional, and environmental parameters together within a consistent optimization framework is required.

Related Works

Advances in urban design optimization have increased the significance of integrating environmental performance into spatial organization through computational methods (Table 1). Wang et al. (2025) and Meng et al. (2024) used NSGA-II-based multi-objective frameworks to optimize building spatial configuration and high-rise housing for thermal comfort, showing important improvements in UTCI values. Likewise, Lin et al. (2023) validated thermal comfort results in cold-climate green spaces using simulation tools on environmental performance, highlighting the role of organizing the vegetation. Another optimization study on green space placement was conducted by Zhang et al. (2017) to demonstrate the thermal and visual benefits of spatially clustered green spaces. Zhao & Zhang (2023) further contributed by comparing the energy and thermal effects of cool and green roofs across climate zones, emphasizing the daytime efficiency of cool roofs in decreasing surface temperature and their potential in urban heat island (UHI) mitigation. In the urban form section, Zhu et al. (2024) presented a Modified Competitive Search Algorithm (MCSA) that outperformed traditional methods in optimizing massing variables such as orientation and compactness. Yang et al. (2023) integrated historical and environmental targets into heritage block design by using NSGA-II and shape grammar. Moreover, Tay et

Table 1. Literature review table.

Author (Year)	Objective	Constraints	Methods	Parameters	Findings
This Paper	Solar radiation minimization on terraces by considering specific design constraints	Near Feasibility Threshold (NFT)	CMA-ES, RBFOpt, GA	Mass size, mass placement	Only with CMA-ES solar load is minimized on terraces via optimal placement. The optimized result had 11–26% improvement in solar gain in comparison to the benchmarks.
Wang et al. (2025)	To simultaneously optimize UTCI and indoor visual performance (sDA, ASE, GVI) in green spaces between residential buildings	No explicit constraint-handling approach used.	NSGA-II +Wallacei	Tree type, crown shape, height, spacing, planting layout, canopy overlap	Improved UTCI by 1.31%, sDA by 6.07%, GVI by 26.27%
Wang et al. (2025)	To minimize UTCI in early-stage green residential layouts and optimize energy and comfort performance	No explicit constraint-handling approach used.	ANN + Genetic Algorithm (GA)	Building count, geometry (width, depth, height), WWR, orientation, climate zone	Optimized layout reduced total load by 40.7%; UTCI improvements ranged between 12–21%
Zhang et al. (2017)	Optimize green space placement to reduce urban heat island	No explicit constraint-handling approach used.	GIS + Remote sensing	LST (Land Surface Temperature), Ti (buffer temp), βi (direct cooling), δik (indirect),	Clustered greenspaces → +6.7°C local daytime cooling; dispersed → +0.5°C regional; 96% of day–night trade-offs captured
Zhu et al. (2024)	Urban building form optimization using MCSA	No explicit constraint-handling approach used.	Modified competitive search algorithm	Latitude, number of floors, N–S aspect ratio, grid azimuth, canyon ratio, building spacing	Pavilion forms optimal at 48° latitude with up to 9 floors; spacing and height improve performance; FAR & absorptivity climate-sensitive.
Yang et al. (2023)	Heritage-sensitive block design optimization	No explicit constraint-handling approach used.	NSGA-II + shape grammar+ K-means clustering, Pareto front analysis	Density, green ratio, solar access	Balanced historical context with environmental goals
Showkatbakhsh et al. (2022)	MOEA result selection framework for urban design	No explicit constraint-handling approach used.	MOEA, Pareto clustering, Utopia-point selection, equal-weight filtering, subjective phenotypic evaluation	Shadows, volumetric connections, skyways, built volume; phenotypic indicators	Fitness improved for all objectives; framework maintains solution diversity
Li et al. (2022)	To optimize additional building volume in urban renewal by balancing FAR increase and solar constraints.	Introduces a custom constraint-handling concept called *NFAR* (Net Floor Area Ratio), allowing shading if capacity gain outweighs shaded area.	GA+Wallacei	Floor Area Ratio (FAR), Average Solar Radiation (ASR), Shaded Façade Area (RBFA), building orientation	Mixed mode ↑ FAR by ~98%, vertical by ~59%, horizontal by ~36%. ASR decreased by 8–15% across modes.With 10–20% shaded area, up to 5× added floor area gained.

Table 1. Continue.

Author (Year)	Objective	Constraints	Methods	Parameters	Findings
Tay et al. (2024)	Review of urban design optimization research	No explicit constraint-handling approach used.	PRISMA-based systematic review of 123 papers from 2012–2022	Solar access, wind, energy use, land use, visibility, density	Mainly focus on environmental/spatial goals (~70%). Few use surrogate models (~20%) or constraint-handling methods
Lin et al. (2023)	To assess the UTCI and perception in open spaces near the Yellow River using different planting configurations	No explicit constraint-handling approach used.	Ladybug + field validation	Air Temperature, Globe Temperature, Relative Humidity, Air Velocity, Vegetation Volume, Mean Radiant Temperature	Strong fit between measured and simulated UTCI (R^2=0.936); AH planting had best cooling.
Meng et al. (2024)	To optimize seasonal outdoor thermal comfort (UTCI) in high-rise residential layouts in cold inland climates	No explicit constraint-handling approach used.	NSGA-II + Sobol + GBM	Building spacing, orientation, length, height, and layout density	UTCI improved to 25.51°C (summer), −14.02°C (winter), −6.41°C (spring).

al. (2024) and (Showkatbakhsh & Makki, 2022) emphasized the increasing demand for user-centered, multi-objective approaches and the significance of incorporating subjective decision-making into urban form algorithms. Li et al. (2022) evaluated capacity increases and trade-offs in solar performance through volumetric additions using evolutionary methods, while Wang et al. (2025) also presented AI-driven platforms for residential configuration optimization.

While previous research has largely focused on optimizing green spaces, building orientations, and urban form for outdoor thermal performance, the specific spatial and environmental potential of cool terraces, as semi-public, outdoor spaces, remains underexplored. Furthermore, despite the increasing number of studies on performance-based design optimization in architectural contexts, a critical gap in the literature is the reliance on a single optimization algorithm within most studies. This creates a limitation, especially considering the impacts of the No Free Lunch (NFL) Theorem, which asserts that “when averaged over all possible problems, all algorithms perform equally well” (Wolpert & Macready, 1997). Therefore, it is impossible to know in advance which algorithm will perform best for a specific design problem. To address these limitations, this study proposes a computational design framework demonstrating how terrace morphology and placement can be strategically adapted to reduce heat stress and improve outdoor thermal comfort. Moreover, this study evaluating the performance of three different algorithms clearly demonstrates the limitations of both GA and RBFOpt in effectively solving the specific performance-oriented design challenges within terraced housing scenarios. By conducting a comparative evaluation of widely used algorithms, this study addresses this methodological shortcoming and provides significant insights for future computational design studies.

Novelty of the Study

This study proposes a computational design framework to identify well-performing cool terrace alternatives, with respect to constrained functions, considering three different optimization approaches in the early design phase. The study aims to identify convenient optimization methods for allocating living spaces while identifying satisfactory solar radiation results. Within the scope of the research, the sizes and locations of residential mass blocks on a specified grid structure are parameterized in the model. The optimization process aims to minimize the total solar radiation on the terraces. The success of different optimization algorithms on the targeted criteria of the model is evaluated. In line with the observed criteria, the spatial layout of the apartment units is prevented from overlapping with each other and the central circulation core, while simultaneously maintaining the minimum total construction area. In addition, the success of this optimization approach is compared and evaluated with the results of the benchmark scenarios. The study ultimately contributes to a computational design process that supports decision-making for environmentally sensitive and harmonious cool terrace housing layouts. The rest of the paper is structured as follows: Section 2 presents the methodology, Section 3 reports the results and discussion, Section 4 compares the optimized solution with benchmark scenarios, Section 5 discusses the results, and Section 6 concludes the paper.

METHODOLOGY

The methodology of this study (Figure 1) consists of four phases: (i) Development of the parametric model, (ii) evaluating solar radiation, (iii) optimization process to identify a suitable solution.

Each phase is explained in the following subsections.

Development of the Parametric Model

The housing model is based on a 25x25 meter grid, with a 5x5 meter central circulation core occupying a fixed position (Figure 2). The height of apartments and circulation areas on one floor is determined as 3 meters. Six apartment units are positioned dynamically within the grid structure, with their dimensions and movement (in the x and y directions) considered as optimization parameters. Four constraints are identified with the NFT component in Grasshopper. One of these is that the apartments should not overlap with each other during settlement. Likewise, the apartments should not overlap with the circulation area. In this context, the intersection areas between the base surfaces of the six apartment masses were constrained to be zero square meters and integrated as a constraint into the NFT component. Similarly, the six intersection areas between the bases of these apartment masses and the base of the circulation were also constrained to be zero and included as an additional restriction. Thirdly, all apartments should be located within the boundary of the configuration. To enforce this condition, an additional intersection area constraint was integrated into the model. Specifically, the intersection area between the base of each mass and the designated boundary area was required to be equal to the full area of

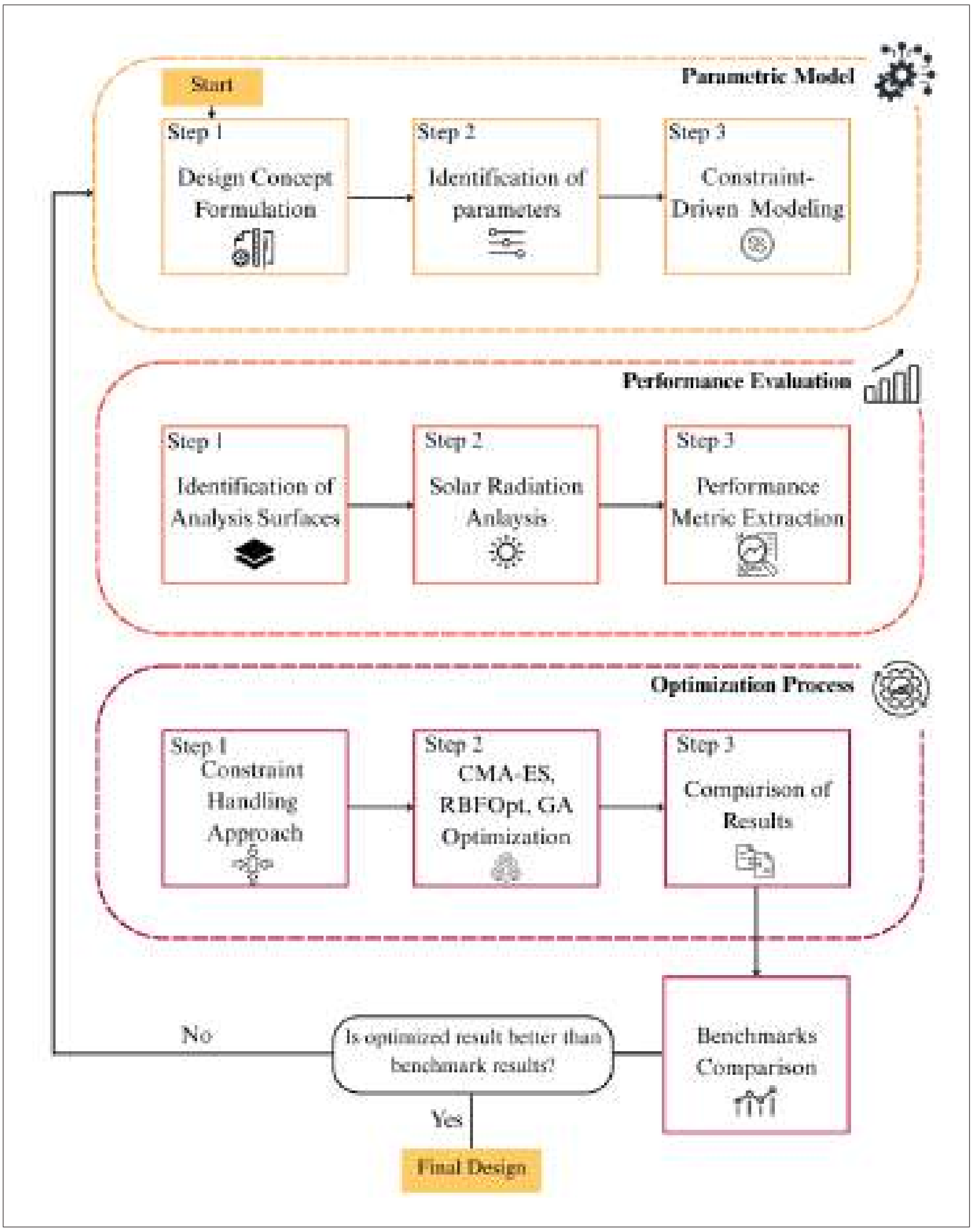

Figure 1. Methodology chart.

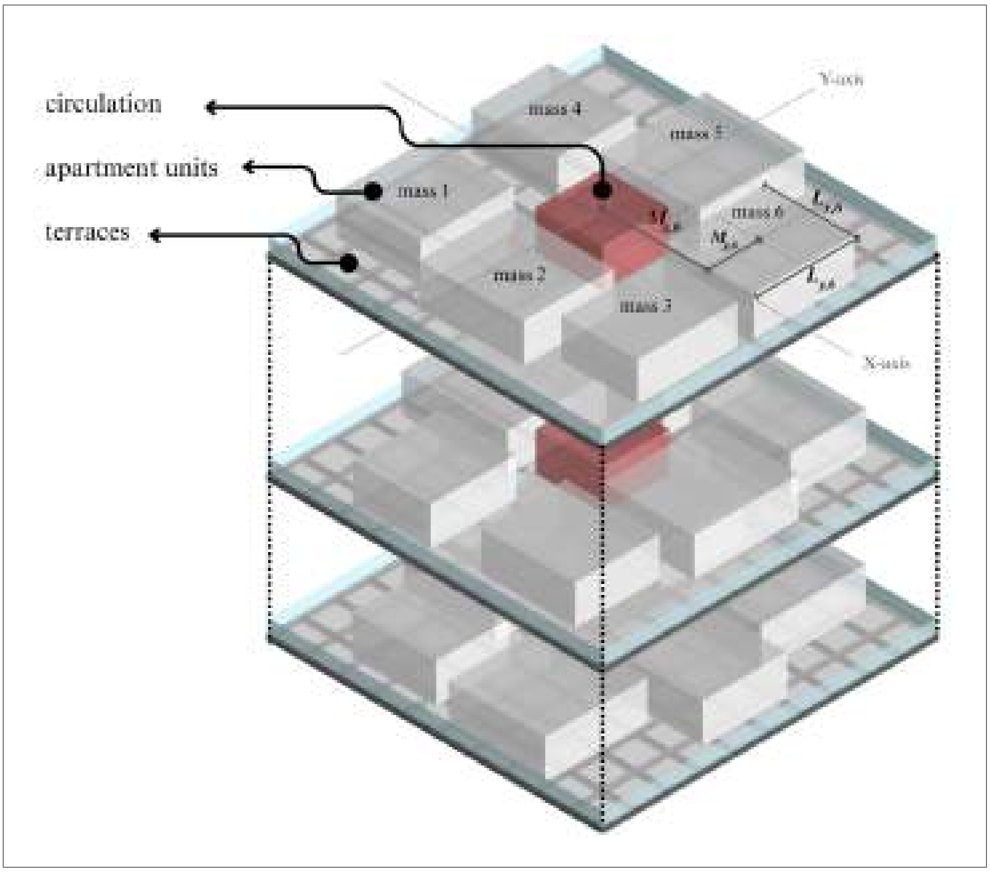

Figure 2. Developed model organization.

that mass. If the intersection area was calculated to be less than the block's own footprint, it indicated that part of the volume extended beyond the defined boundary, thus violating the constraint. Finally, considering the dimensions of the grid structure, the minimum total floor area of the apartments was determined as 300 m² to establish the balance between terrace and closed area. According to these constraints, sample successful and unsuccessful spatial layouts are demonstrated in Figure 3.

As indicated in Table 2, four parameters are assigned to every six masses: Length measurements along the X and Y axes and movement distances in the X and Y directions. These parameters are designed to be dynamic and adjustable, considering the constraints determined during the optimization process. In total, 24 design parameters are recorded during the optimization. The length values (X and Y) of each mass are set to be allowed to change continuously between 5m and 10m, allowing for form flexibility in response to performance feedback. Meanwhile, the movement values (X and Y axes) are limited to the range of -12.5m to +12.5m. This allows the six masses to move onto the grid system surface and find spatially efficient positions, allowing the remaining terraces to be created in a more solar-efficient way.

Evaluating Solar Radiation

Solar radiation is electromagnetic energy emitted from the sun and reaching the earth's surface and is a factor that has a crucial impact on the thermal and daylight performance of buildings. Most researchers suggest that sunlight plays a positive role in improving thermal comfort, health, and energy performance (Zhang et al., 2016). While traditional design methods depending on solar metrics often rely on simplified formulaic calculations or user intuition and experience, this approach is insufficient for spatial systems like housing designs with integrated terraces. Like free-form buildings that do not have exact geometric forms and therefore need detailed simulation-based evaluations for accurate solar performance assessment (Vizotto, 2010), the parametric model proposed in this study uses solar radiation analyses to optimize the positioning and dimensions of apartment units and terraces.

Solar radiation has a significant effect on the thermal performance of terraces. Especially in high-density urban areas, the direct impact of solar radiation on terrace surfaces means an increase in surface temperatures. This situation causes negative effects on indoor thermal comfort and energy consumption of the building. A study conducted by Ismail et al. (2021) evaluated the effects of solar radiation on the vertical surfaces of modern terrace houses. The study suggested that high solar ra-

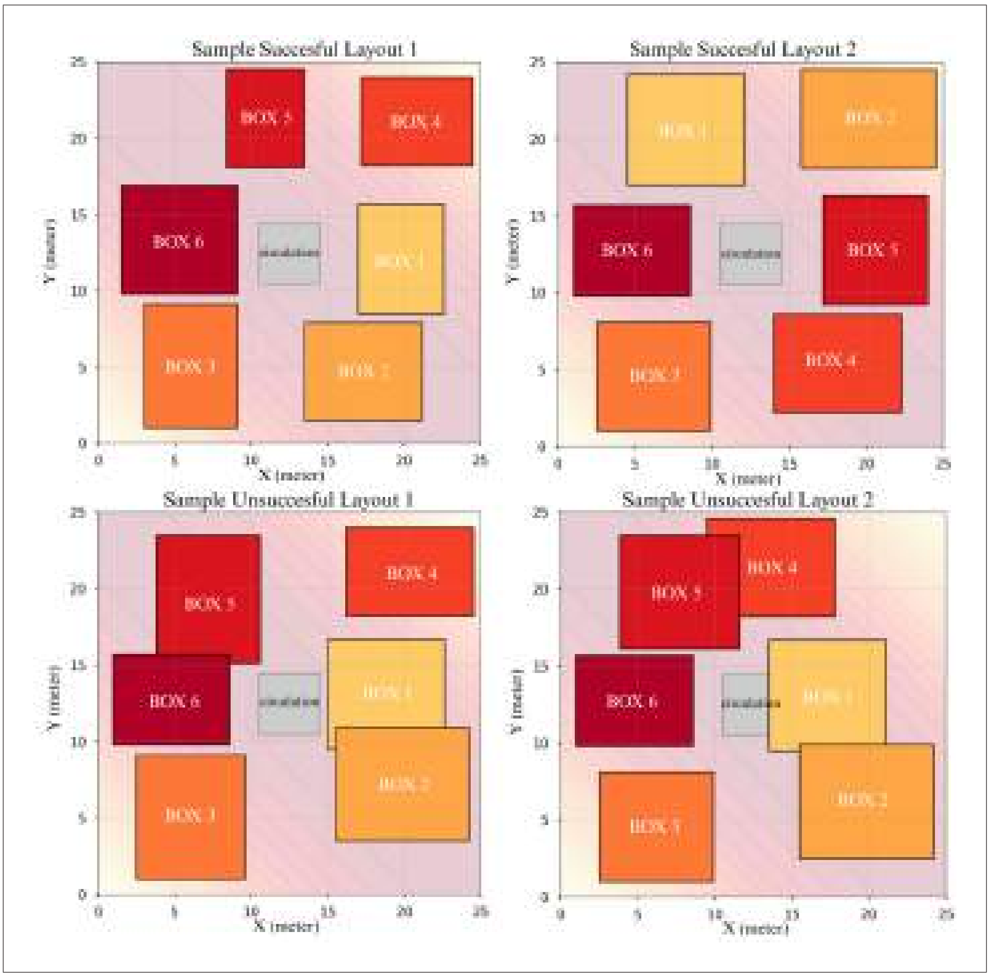

Figure 3. Sample layouts.

diation significantly increases surface temperatures, which can negatively affect indoor thermal comfort. Similarly, another study conducted by Kawasaki et al. (2020) addressed the role of solar radiation on the thermal behavior of buildings through reflection and re-emission in different climatic zones. The study emphasized that reflected solar radiation creates heat accumulation, especially in the lower layers, and this can increase the cooling load inside the building. Therefore, considering the vertical distribution of solar radiation in terrace designs is of critical importance in terms of ensuring thermal comfort.

In this study, solar radiation analysis is integrated into the optimization framework to improve the thermal performance of terraces. The main objective is to minimize solar radiation on terraces while simultaneously optimizing the spatial organization and dimensions of apartment units, thereby facilitating the creation of "cool terraces." Solar radiation simulation was conducted using the Ladybug Tools plug-in in Grasshopper. The simulation used the Radiance-based sky matrix method, which enables high-resolution cumulative radiation analysis over custom-defined periods. The input weather data was provided from the EnergyPlus™ EPW file for Izmir (TRY 2018), ensuring location-specific environmental accuracy. The Perez sky model was employed through the Sky Matrix component to account for both direct and diffuse solar radiation de-

Table 2. Parameters.

Parameters	Explanation	Boundary	Units	Notes
$M_{x,i}$	movement of mass *i* along X-axis	[−12.5, +12.5]	m	
$M_{y,i}$	movement of mass *i* along Y-axis	[−12.5, +12.5]	m	*i*=1…6
$L_{x,i}$	length of mass *i* in X-axis	[5, 10]	m	
$L_{y,i}$	length of mass *i* in Y-axis	[5, 10]	m	

rived from hourly weather data. The analysis period was set from July 1st to August 1st, covering the critical summer days to capture peak solar radiation gain. Radiation calculations were performed using the Ladybug Incident Radiation component, with terrace geometries dynamically generated through the parametric design model. Simulation results were computed using a grid size of 0.6 a minimum threshold of 0.1 for radiation values, producing cumulative irradiation values (in kWh/m²) on terraces. The output was used as a performance criterion during the design generation and optimization phases to minimize solar radiation gain on terraces.

Optimization Process

The optimization process involves three different optimization algorithms, RBFOpt and CMA-ES, using the Opossum plug-in and the GA in the Galapagos plug-in. RBFOpt presented by Costa and Nannicini (2018) is mostly used for computationally expensive simulations that suggest a near-optimal solution with a limited number of function evaluations. CMA-ES proposed by Hansen & Ostermeier (2001) is one of the best-performing optimization algorithms in the architectural design domain, as it has been utilized in many studies. On the other hand, GA is also one of the most well-known and utilized optimization algorithms in parametric design models, as it is involved in Grasshopper3D. Finally, Optimus plugin's near-feasibility threshold (NFT) (Coit & Smith, 1996) module is applied to all optimization processes as it suggests an adaptive constraint handling strategy, significantly effective when compared to constant penalty functions. All approaches are applied to determine the most efficient layout of the apartment units to minimize solar radiation on terrace values while satisfying design constraints.

Radial Basis Function Optimization (RBFOpt): Designed to deal with computationally intensive optimization problems, RBFOpt is a model-based algorithm presented by Costa and Nannicini (2018). It builds an approximate model of the objective function by interpolating existing samples and then estimates new promising candidates. This method significantly decreases the number of expensive function evaluations. RBFOpt distinguishes itself from other existing model-based open-source algorithms by incorporating a validation-driven strategy for model selection and by allowing the use of approximate evaluations to speed the optimization process, even if those evaluations consist of a degree of noise. RBFOpt has been effectively implemented in architectural design optimization. For instance, Ratajczak et al. (2023) used this method in the GENIUS project to optimize building form and window-to-wall ratio of an office building, targeting to maximize solar performance and minimize overall energy consumption. Moreover, Zhang, et al., (2020) applied RBFOpt to optimize the aerodynamic shape of a conceptual high-rise building. The optimization identified forms with significantly reduced wind-induced pressures and improved overall structural efficiency compared to baseline geometries. In this study, the optimization process is carried out using Opossum v3.0.0 including the RBFOpt algorithm with its default parameter settings.

Covariance Matrix Adaptation Evolutionary Strategies (CMA-ES): The CMA-ES algorithm, originally introduced by Hansen & Ostermeier (2001), is a widely used method in evolutionary optimization because of its adaptive approach to exploring the solution space. It dynamically arranges the scale of the search in response to previous solution results by updating the parameters of a multivariate normal distribution—namely, the mean, standard deviation, and entire covariance matrix—within the decision variable domain. Recently, this algorithm has been used to solve several design problems, e.g., Fernandes et al. (2023) used the CMA-ES algorithm to optimize the design of cable-stayed bridges, targeting to minimize construction budget while guaranteeing structural stability and durability. Turrin et al. (2011) used CMA-ES to generate shell structures that achieve maximum structural efficiency. Kaveh et al. (2011) used it to optimize the size and topology of steel truss structures. The results demonstrate the algorithm's applicability to performance-driven structural form-finding in architecture and engineering contexts. In this study, the optimization process is conducted using Opossum v3.0.0, which integrates CMA-ES as an open-source Grasshopper plug-in, relying on its standard optimization settings.

Genetic Algorithm (GA): Galapagos is a solver incorporated in Grasshopper that utilizes a simple Genetic Algorithm (GA) and Simulated Annealing (SA) for optimization. It develops a population of solutions depending on selection, crossover, and mutation without relying on surrogate models. It enables the user to define a set of input parameters that the algorithm can manipulate (Rutten, 2013). Galapagos GA allows users to potentially investigate the performance metrics and morphologies of all evaluated design options during the optimization. This algorithm has also been utilized in several architectural design processes; for instance, Özerol and Selçuk (2023) used GA to optimize the bioclimatic facade design of an office building depending on solar radiation, determining the most efficient and appropriate alternative according to sun positioning. Ida and Kimura (2003) used GA to optimize the spatial organization of a floor plan within a slicing/non-slicing structure. Their improved approach outperformed existing methods in convergence speed and layout accuracy, delivering more efficient and practical architectural floor plan designs. Taleb et al. (2024) used GA in the design of urban block morphology in a hot-arid climate, aiming to maximize floor area while minimizing exposure to solar radiation. The genetic algorithm-based approach enabled the identification of urban layouts that responded effectively to environmental constraints.

Near Feasibility Threshold and Constraint Handling: Near Feasibility Threshold (NFT) is a technique used to effectively manage constraints in optimization processes. For complex constrained optimization problems, Ekici et al. (2021) highlighted the necessity of using advanced constraint-handling techniques. In response, this study uses the NFT adaptive penalty method presented by Coit and Smith (1996), which provides as an improvement over traditional constant penalty function. The main idea of the NFT approach is to identify a threshold distance from the feasible region, promoting exploration within this region and its vicinity, while preventing and penalizing solutions that fall beyond it. Equation 1 describes the penalized fitness function using NFT as;

Near Feasibility Threshold

In this formulation, denotes the fitness function, while is the violation of constraints. The parameters and are user defined which are taken as 2 and 0.04 respectively. refers to the upper threshold for the NFT taken as 0.1; and *g* indicates the generation or iteration number within the optimization process. To provide a reasonable comparison between the algorithms in the optimization processes of RBFOpt, CMA-ES and GA, the NFT approach is also included in the optimization process. The Optimus plug-in v1.0.2 provides an open-source NFT component that can work with other optimization plugins in Grasshopper.

Cool terraces designed with the goal of minimizing solar radiation are subjected to a series of constraints during the optimization process. In the developed model, to deal with determined constraints, NFT is used. NFT is utilized to manage constraints effectively, ensuring that intersections of boxes are eliminated, and that minimum floor area requirements are met. The penalty function approach within NFT facilitates a seamless optimization process. NFT balances the constraints set with the optimized goal, preventing any obvious violation of the constraints. Thus, it allowed the solution to remain within the threshold of close feasibility.

RESULTS

In the optimization results, it is observed that only the layout produced by CMA-ES complies with the specified design constraints. Figures 4, 5, and 6 show the parameters of the results obtained at the end of the iterations. The last recorded result shows the layout and dimensions of the apartments in the recorded parameters. In the RBFOpt and GA optimization results, it is observed that the apartment units are settled without adhering to the specified constraints, such as not exceeding the total indoor area and staying within the specified boundaries. As seen in Figure 7, while CMA-ES demonstrated stable convergence towards feasible, lower radiation results, RBFOpt and

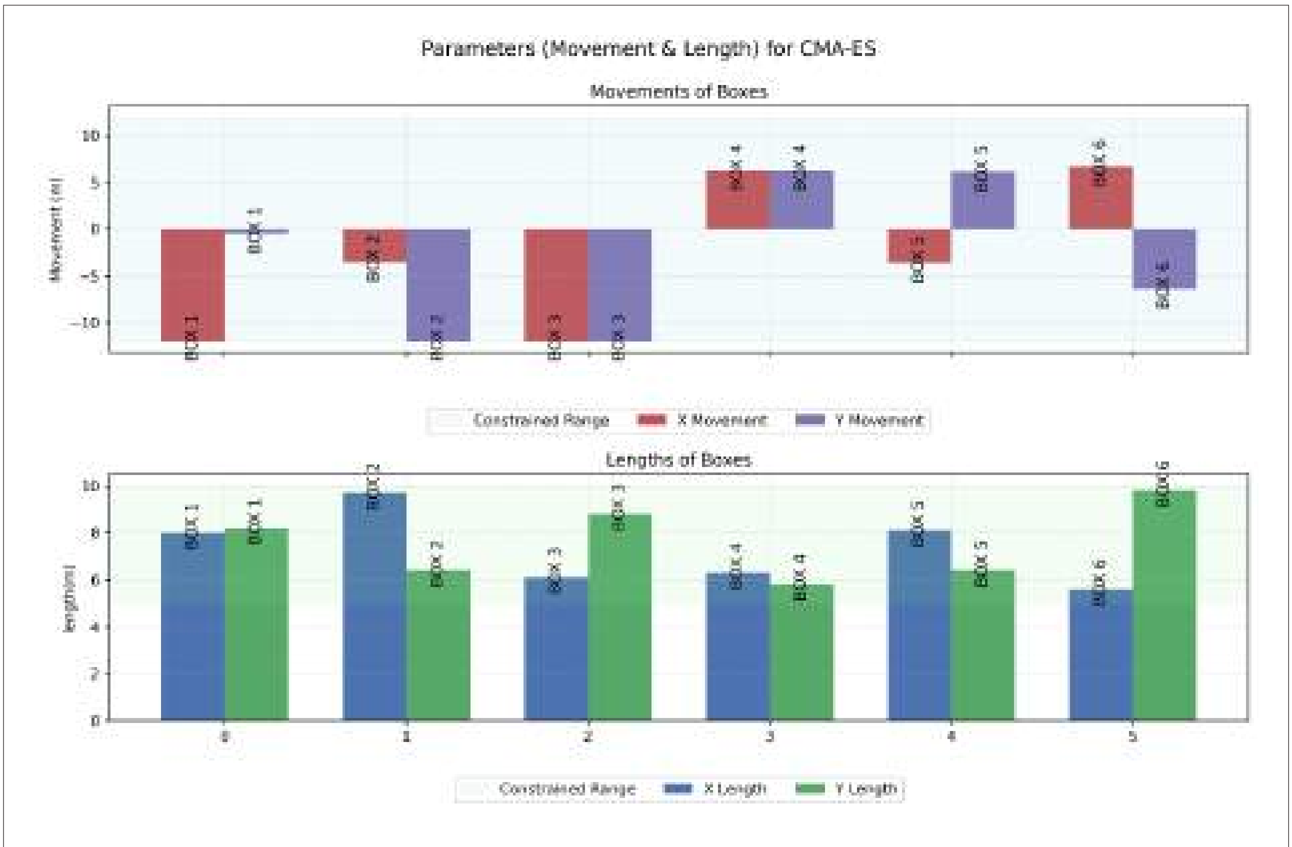

Figure 4. Parameters for CMA-ES optimized result.

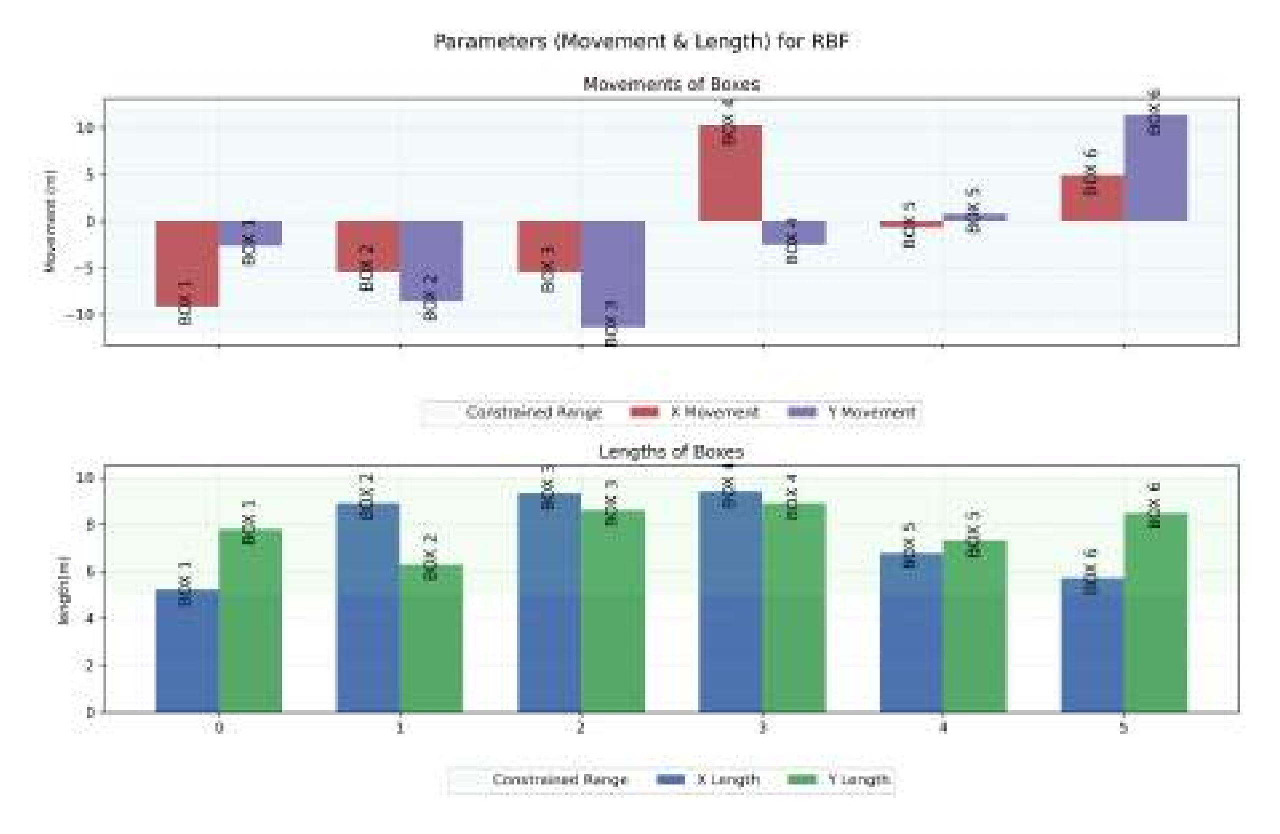

Figure 5. Parameters for RBFOpt optimized result.

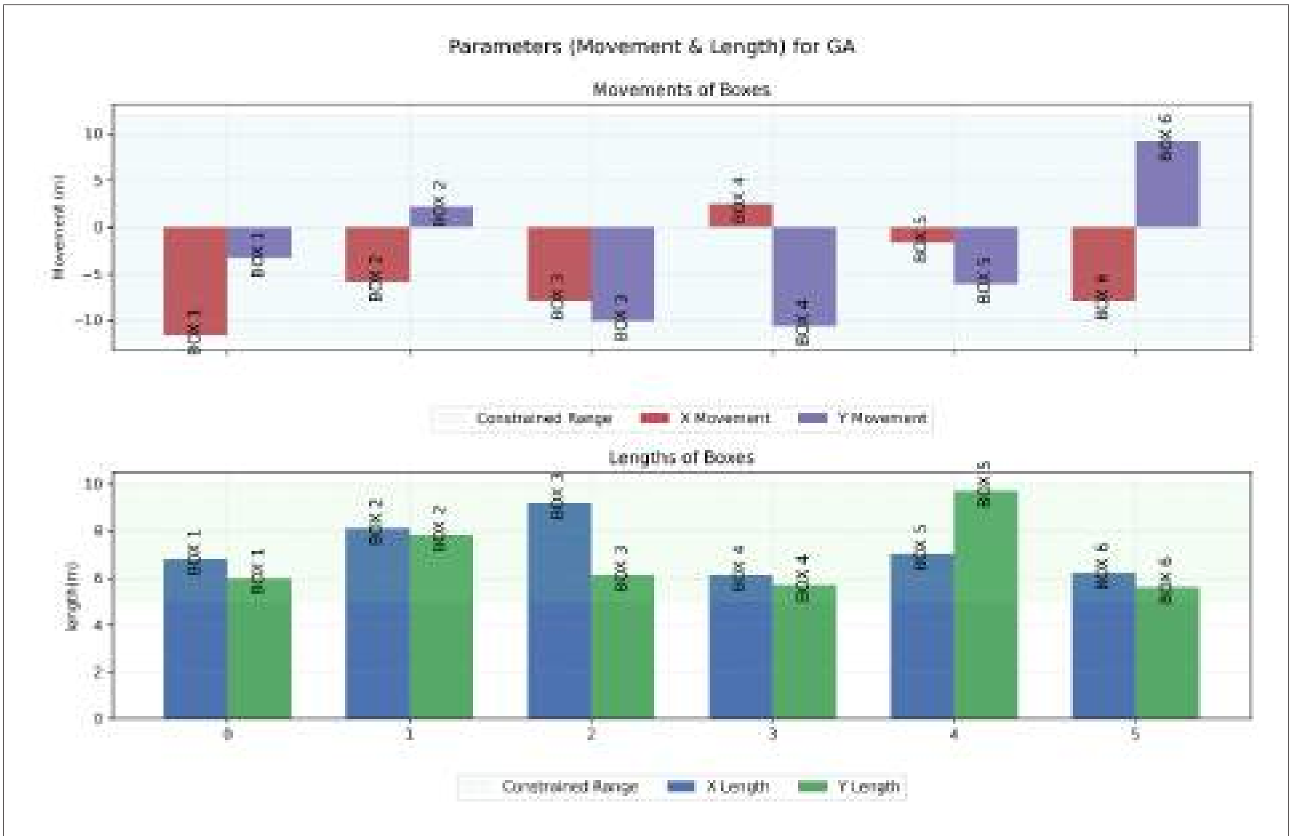

Figure 6. Parameters for GA optimized result.

GA were not successful in maintaining constraint compliance and convergence throughout the optimization process. This result demonstrates that algorithm selection is not only related to performance criteria but also to compatibility with the problem structure, especially when physical constraints and geometric form requirements are included.

CMA-ES Optimization Results

The optimization process using Opossum CMA-ES has made considerable progress (Figure 8). The optimization was performed with 50 populations and progressed through 2500 iterations. One of the most remarkable achievements was the positioning of the six building masses within boundaries and the elimination of overlaps with the circulation area and each other (Figure 9). The area constraint that the area of the six apartments should be over 300 m² was also successfully met, with 324 m². The total indoor floor area was 349 m², including the circulation area. Considering that the previously defined grid structure system was 625 m², the remaining 269 m² outside the apartments and circulation area was allocated to cool terraces. Thus, a balanced open space to closed space ratio was achieved. The optimization successfully minimized the solar radiation on the terraces, which is one of the primary performance criteria. During the optimization period, the total solar radiation on the cool terraces was reduced from slightly above 2050 kWh/m² to 1830.1 kWh/m² with an improvement of approximately 11%. Overall, CMA-ES achieved significant improvements in both design feasibility and optimization of the specified performance criteria. The results confirmed the ability of CMA-ES to manage a complex optimization process with high precision and allowed it to be considered as a reliable tool for the set study objectives. The CMA-ES algorithm yielded the only feasible optimization result with the value of 1830.1 kWh/m². The performance of this optimized configuration was subsequently evaluated through comparative benchmarks resulted in higher radiation values.

RBFOpt Optimization Results

As another part of the comparative optimization methodology, an additional optimization was conducted using the RBFOpt algorithm integrated into the Opossum solver in Grasshopper. The optimization constraints were set to have a minimum total building area (300 m²) and to be located within the predefined system boundaries without intersecting each other. This was carried out for 2500 iterations with the aim of minimizing the cumulative solar radiation on the terrace surfaces. However, the optimization process could not successfully converge. Although the total covered floor area constraint of 300 m² was met with a result of 358 m², there were significant violations of other critical constraints. The massing configuration resulted in a large overlap area of 164 m² between the six units, suggesting a failure in the overlap prevention mechanism. In addition, 106 m² of the six total masses were located outside the boundary of the specified structure, which violated the spatial boundaries set in the design framework (Figure 10). In terms of performance results, the solution had a solar radiation value of 2608.8 kWh/m² (July 1 to August 1), which was much higher than the optimized result (CMA-ES). Overall, these results show that the RBFOpt algorithm is not effective in the optimization process of the proposed model with constraints in this context. The inability to achieve both constraint compliance and solar radiation minimization at the

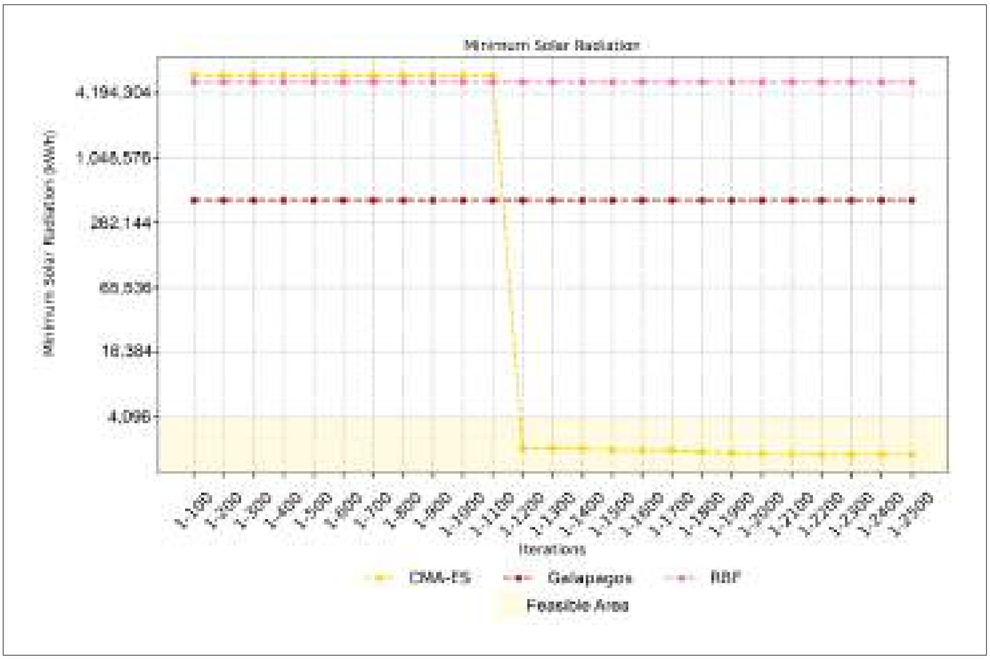

Figure 7. Minimum solar radiation graph for each algorithm.

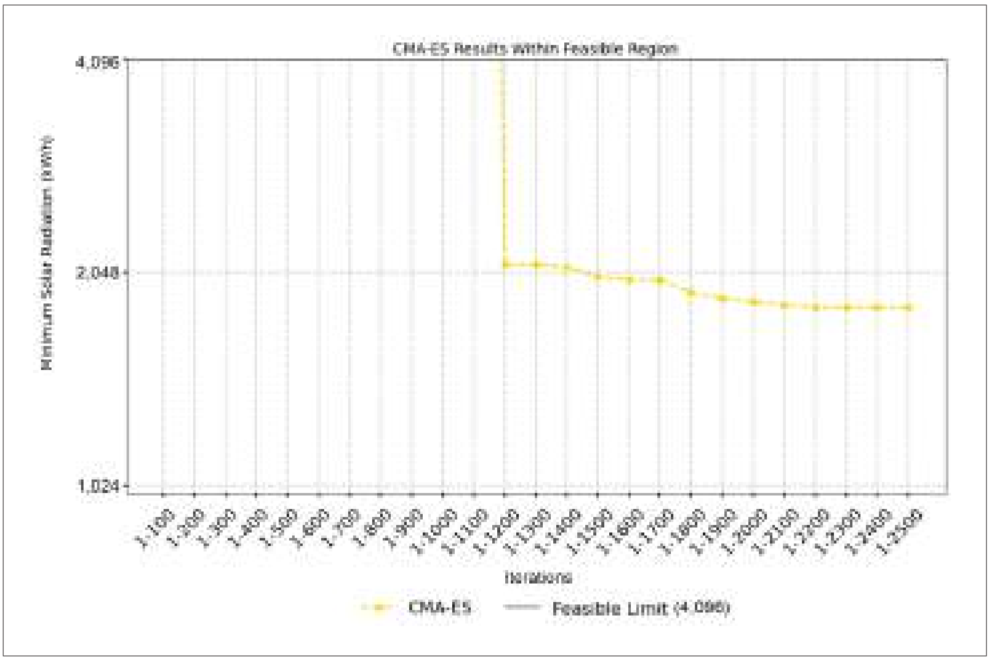

Figure 8. Minimum solar radiation graph for CMA-ES.

same time strengthens the selection of the CMA-ES algorithm as a more suitable optimization strategy for this study.

GA Optimization Results

As part of the comparative methodology, another optimization attempt was performed using the Galapagos evolutionary solver in Grasshopper. The optimization was run for 50 iterations with 50 populations. It aimed to minimize the cumulative solar radiation generated on the terraces while meeting the spatial basic design constraints of minimum total built-up area (300 m²) and within the defined boundaries. The optimization process failed to produce satisfactory results. Many constraint violations were observed in the generated solutions (Figure 11). An overlap of 62.5 m² occurred between the masses, indicating that the algorithm was unable to successfully implement the overlap constraint. Additionally, the building masses were located outside the system boundaries, resulting in a constraint violation. The total floor area of the six masses remained at 297.4 m², which is below the minimum area constraint. The solar radiation value for the period July 1 to August 1 is 2505.1 kWh/m², which was significantly higher than the optimized result (CMA-ES). These results indicate that GA is not sufficiently suitable for the constraint-weighted optimization process of the proposed model within the given parameter structure and con-

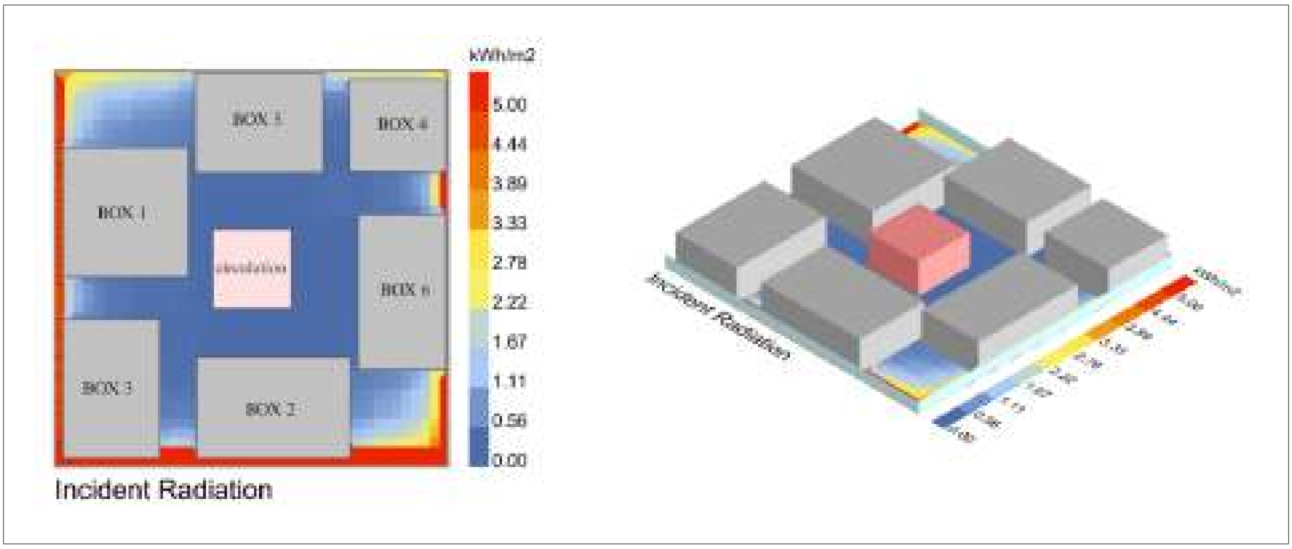

Figure 9. CMA-ES optimization results.

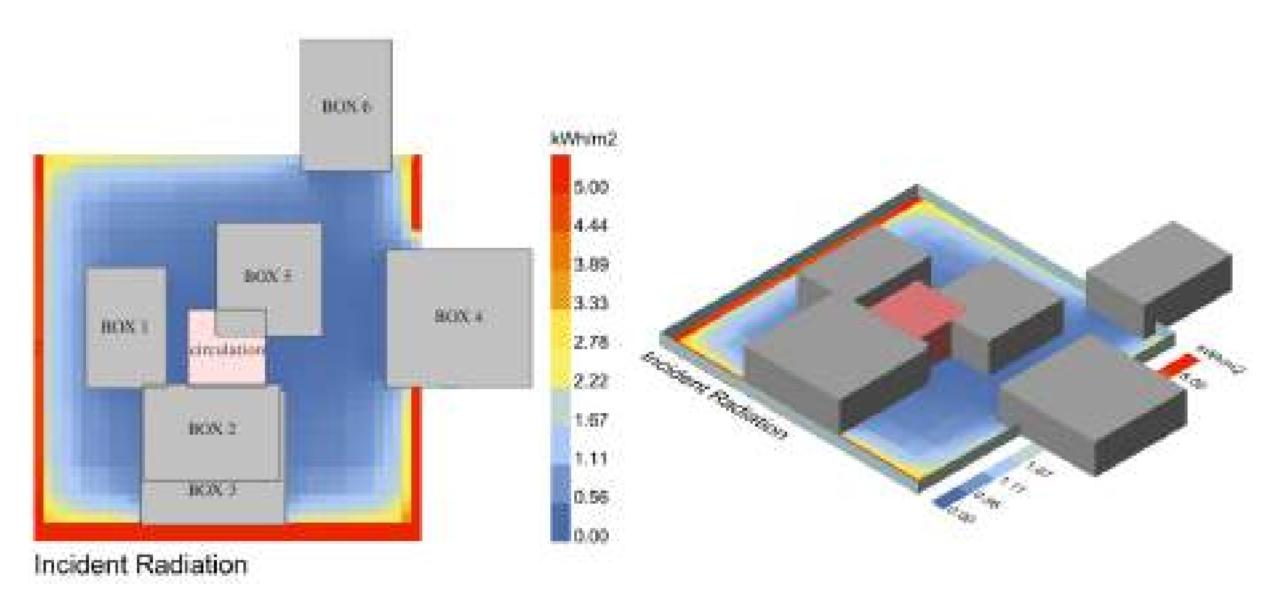

Figure 10. RBFOpt optimization results.

straint framework. This reinforced the decision to continue working with CMA-ES, which achieved significantly higher convergence quality and constraint compliance.

Comparison of Benchmarks and Optimized Layouts

The primary objective of this comparison is to evaluate the effectiveness of the optimization process in creating environmentally responsive architectural designs by comparing them with three different benchmark scenarios. Each benchmark has a different spatial configuration strategy: (1) Masses located toward the center of the structure, (2) masses pushed toward the facades, and (3) a homogeneously distributed organization. By comparing the optimized result (CMA-ES) with these benchmark configurations—varying in both positions and sizes—this study emphasizes how form generation can be directed towards enhanced environmental performance. The contribution is to provide a structured framework to evaluate the adaptability and performance of optimization methods in early phases of design, particularly in relation to solar radiation exposure and terrace shading.

The design goal in the first benchmark scenario is to locate the masses as close as possible to the circulation core in the middle while ensuring that each of the six masses has access to the cool terrace. Care is taken to ensure that the areas of the six masses were over 300 m², as 330.4 m². This design approach allowed for a compact spatial layout and even out-

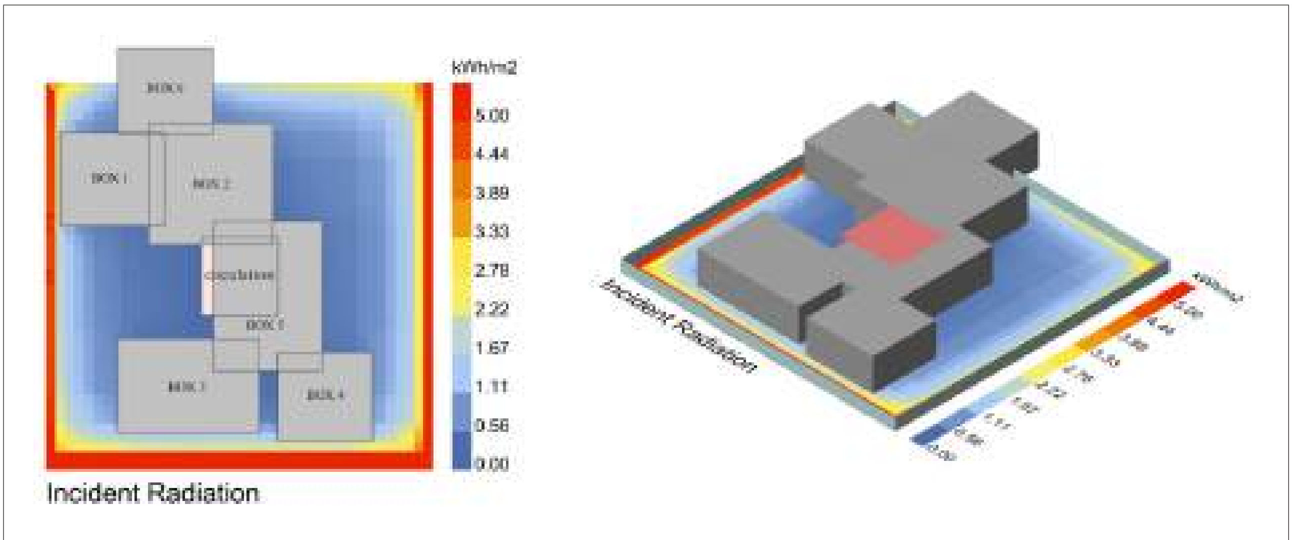

Figure 11. GA optimization results.

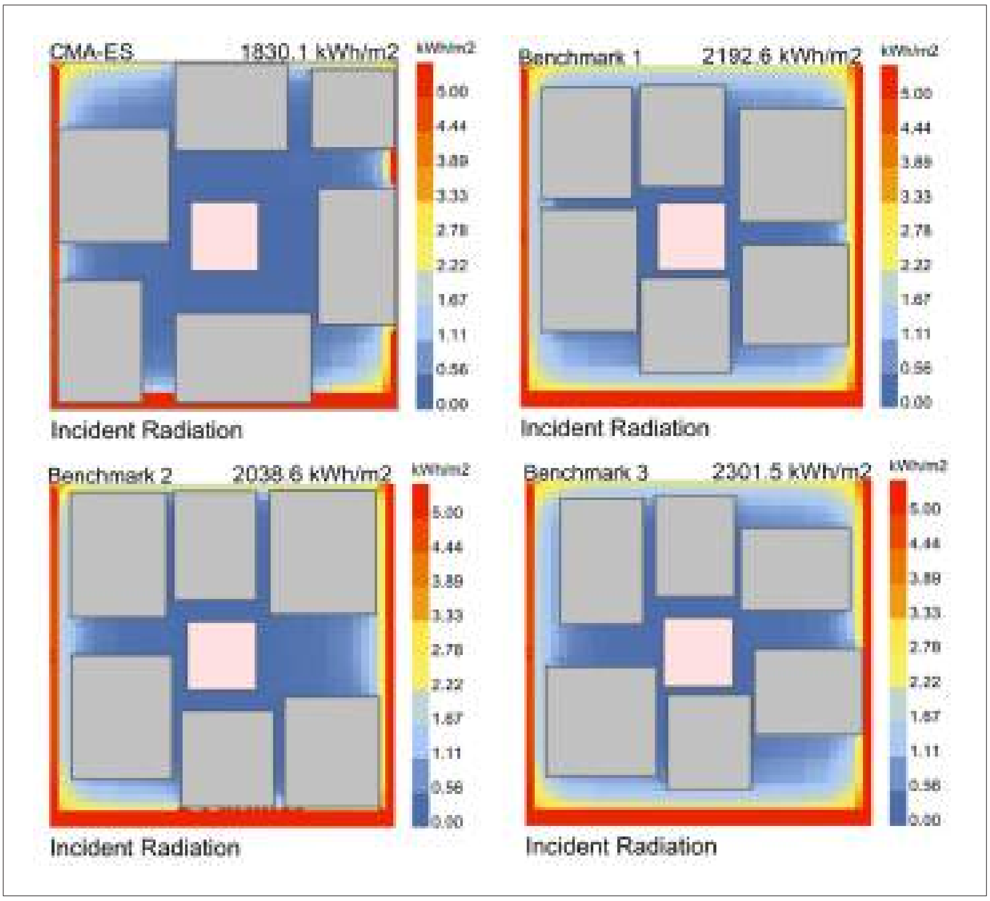

Figure 12. Benchmarks and optimized result comparison.

door space distribution. However, the terraces were not strategically shaded and were exposed to more solar radiation. The total solar radiation observed on the cool terraces was measured as 2192.6 kWh/m² for a one-month period. However, the CMA-ES optimized result achieved a lower solar radiation value of 1830.1 kWh/m², a reduction of 16.51 %.

In the second benchmark, the six mass units were positioned as close to the facade as possible along the outer boundaries and were removed from the central area. The main aim of this perimetric configuration was to provide maximum exposure to the sun and to reduce mutual shading between the masses. By placing each housing unit adjacent to a facade edge, the design created a more open and ventilated arrangement and provided more environmental interaction for the cool terrace zones. This layout produced a total gross construction area of 351 m², meeting the minimum area constraint. However, due to the increased exposure and dispersion of the masses, the total solar radiation to the cool terraces increased to 2038.6 kWh/m². While this scenario provides maximum façade interaction and terrace openness, it performs less efficiently in terms of solar heat gain reduction. On the other hand, the optimized layout with CMA-ES achieved a lower solar radiation value of 1830.1 kWh/m², which is a decrease of 11.37%.

In the third benchmark, the six building volumes are distributed asymmetrically across the grid. This configuration aimed to simulate a less predictable, more organic layout — some masses are positioned close to the façade, some further away, creating different proximity and shadow effects. This spatial variation aimed to evaluate the impact of irregularity on both thermal and spatial performance. The total gross built-up area in this scenario was 301 m², marginally meeting the threshold condition. Incident solar radiation was measured as 2301.5 kWh/m², indicating a moderate improvement compared to the perimetric installation, but still less optimal than the CMA-ES optimized result. The dispersed arrangement created variability in shading and solar access, resulting in a more heterogeneous terrace performance. In fact, the arrangement resulted in approximately 25.8% higher solar radiation compared to the CMA-ES outcome. While the irregular organization introduced variability in shading and solar access, it ultimately caused a more heterogeneous and less efficient terrace performance across the grid.

Figure 12 shows the solar radiation distribution in three benchmark layouts and the optimized result of CMA-ES, indicating the significant improvements achieved through optimization. These findings highlight the contribution of performance-oriented design in mass housing, where computational optimization can improve environmental performance while considering functional and spatial efficiency.

DISCUSSION

This study evaluated the integration of solar radiation performance into the early-stage design optimization of a terraced residential building composed of six apartment units. The optimization aimed to configure six masses with respect to their dimensional (length) and location (movement) parameters to minimize solar radiation on terrace surfaces, with the goal of creating of "cool terraces." Three different optimization algorithms, CMA-ES, GA, and RBFOpt were used and compared over 2500 iterations each. CMA-ES showed the only successful performance, consistently generating spatially feasible organizations that respected constraints. However, GA and RBFOpt algorithms produced configurations that violated these constraints, causing terraces to extend beyond the site boundaries or overlap with each other. This emphasizes the significance of constraint handling capabilities in optimization algorithms when used for complex spatial problems. In addition, the CMA-ES optimized result produced the lowest incident solar radiation value of 1830.1 kWh/m², significantly outperforming the three benchmarks by 16.51%, 11.37% and 25.8%, respectively. These findings are in line with existing literature that emphasizes the importance of computational optimization in passive environmental strategies. Furthermore, the integration of Near Feasibility Threshold (NFT) successfully satisfied design constraints such as non-overlapping volumes and minimum gross floor area requirements, which GA and RBFOpt were not able to achieve in this study. It suggests that more robust global search strategies such as CMA-ES are more suitable for complex multi-constraint spatial problems, especially when parametric variability is high.

The study also revealed distinct spatial trends that challenge traditional architectural assumptions regarding terrace layout. The optimized result with CMA-ES positioned the terrace areas away from the building perimeter towards the inner core, while the residential masses were pushed towards the edges. This configuration contrasts with typical terrace design approaches that prioritize facade proximity but have proven more effective in minimizing exposure to solar radiation. The resulting spatial arrangement functions as a microclimatic courtyard where the apartment volumes act as passive shading elements protecting the terrace surfaces from direct sunlight. In contrast, benchmarks exhibited significantly higher radiation values, displaying more open terrace configurations and less continuous shading. These findings highlight that performance-oriented optimization can create environmentally advantageous terrace designs re-evaluating traditional mass-space relationships. Future work may explore a green terrace alternative or extend the model to a multi-level configuration, since this study focused only on a single-story organization.

CONCLUSION

This study presented a computational framework for optimizing the spatial configuration of six apartment units within a 25×25-meter structure with the aim of minimizing solar radiation on terraces. Using three different optimization algorithms—CMA-ES, RBFOpt, and GA—the study analyzed the performance of each method over 2500 iterations. CMA-ES yields the only feasible result with 1830.1 kWh/m² as a total incident solar radiation — substantially lower than benchmark scenarios as well. Overall, this study reveals that parametric modeling combined with robust optimization techniques can support designers in making informed decisions at early design stages, especially in the context of sustainable housing design. By enabling the exploration of alternative spatial configurations in a controlled parametric environment, the framework contributes to the development of more adaptable and environmentally conscious design strategies without imposing prescriptive formal solutions. In addition, the outcomes underline the significance of choosing proper algorithms that can navigate both performance targets and spatial constraints in architectural design scenarios.

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REFERENCES

Ajtayné Károlyfi, K., & Szép, J. (2023). A parametric BIM framework to conceptual structural design for assessing the embodied environmental impact. *Sustainability*, *15*(15), 11990. https://doi.org/10.3390/su151511990

Bangura, M., & Lee, C. L. (2023). Urbanisation and housing finance nexus: Evidence from Australia. *Habitat International, 139*, 102897. https://doi.org/10.1016/j.habitatint.2023.102897

Bleicher, D. (2019). *Opossum: A Rapid Performance Optimization Tool for Grasshopper*. Retrieved Jan 14, 2025, from https://www.food4rhino.com/en/app/opossum

Coit, D. W., & Smith, A. E. (1996). Penalty guided genetic search for reliability design optimization. *Computers & Industrial Engineering, 30*(4), 895–904. https://doi.org/10.1016/0360-8352(96)00040-X

Costa, A., & Nannicini, G. (2018). RBFOpt: An open-source library for black-box optimization with costly function evaluations. *Mathematical Programming Computation, 10*(4), 597–629. https://doi.org/10.1007/s12532-018-0144-7

Ekici, B., Kazanasmaz, Z. T., Turrin, M., Taşgetiren, M. F., & Sariyildiz, I. S. (2021). Multi-zone optimisation of high-rise buildings using artificial intelligence for sustainable metropolises. Part 2: Optimisation problems, algorithms, results, and method validation. *Solar Energy, 224*, 309–326. https://doi.org/10.1016/j.solener.2021.05.082

Fernandes, G., Lourenço, N., & Correia, J. (2023, April). Reducing the price of stable cable stayed bridges with CMA-ES. In *International Conference on the Applications of Evolutionary Computation (Part of EvoStar)* (pp. 223–236). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-30229-9_15

Hansen, N., & Ostermeier, A. (2001). Completely derandomized self-adaptation in evolution strategies. *Evolutionary Computation, 9*(2), 159–195. https://doi.org/10.1162/106365601750190398

Ida, K., & Kimura, Y. (2003, October). Floorplan design using improved genetic Algorithm. In *International Symposium on Methodologies for Intelligent Systems* (pp. 531-538). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-39592-8_75

Ismail, M. R., Rasli, N. B. I., & Ramli, N. A. (2021). Trends of solar radiation effects on the temperature of vertical surfaces of a modern terrace house. *Heat Transfer, 50*(6), 5982–5995. https://doi.org/10.1002/htj.22158

Kaveh, A., Kalateh-Ahani, M., & Masoudi, M. S. (2011). The CMA evolution strategy-based size optimization of truss structures. *International journal of optimization in civil engineering*, *1*(2), 233-56.

Kawasaki, K., Aoki, T., Sudo, M., & Mizutani, A. (2021). Thermal influence caused by the vertical distribution of reflected solar radiation and re-radiation on the building in various climate areas and its solar shading method. *Japan Architectural Review, 4*(1), 192–201. https://doi.org/10.1002/2475-8876.12184

Li, J., Wang, Y., Xia, Y., Song, Y., & Xie, H. (2022). Optimization of urban block form by adding new volumes for capacity improvement and solar performance using a multi-objective genetic algorithm: A case study of Nanjing. *Buildings, 12*(10), 1710. https://doi.org/10.3390/buildings12101710

Li, S., Liu, L., & Peng, C. (2020). A review of performance-oriented architectural design and optimization in the context of sustainability: Dividends and challenges. *Sustainability*, *12*(4), 1427. https://doi.org/10.3390/su12041427

Lin, J., Jiang, S., Zhang, S., Yang, S., Ji, W., & Li, W. (2023). Thermal comfort in urban open green spaces: A parametric optimization study in China's cold region. *Buildings, 13*(9), 2329. https://doi.org/10.3390/buildings13092329

Meng, Y., Hao, Y., Que, Y., Ren, J., & Liu, Y. (2024). Multi-objective optimization of morphology in high-rise residential areas for outdoor thermal comfort in Yulin City, Northwest China. *Buildings, 14*(6), 1688. https://doi.org/10.3390/buildings14061688

Özerol, G., & Selçuk, S. A. (2023). Bioclimatic façade design based on daylight parameter and optimization of alternatives through genetic algorithms: An office building in Ankara. *PLANARCH-Design and Planning Research, 7*(2), 108–115.

Ratajczak, J., Siegele, D., & Niederwieser, E. (2023). Maximizing energy efficiency and daylight performance in office buildings in BIM through RBFOpt model-based optimization: The GENIUS project. *Buildings, 13*(7), 1790. https://doi.org/10.3390/buildings13071790

Rutten, D. (2010). *Galapagos: An Evolutionary Solver for Grasshopper*. Robert McNeel & Associates.

Rutten, D. (2013). Galapagos: On the logic and limitations of generic solvers. *Architectural Design, 83*(2), 132–135. https://doi.org/10.1002/ad.1568

Showkatbakhsh, M., & Makki, M. (2022). Multi-objective optimisation of urban form: A framework for selecting the optimal solution. *Buildings, 12*(9), 1473. https://doi.org/10.3390/buildings12091473

Singh, P., Kikon, N., & Verma, P. (2017). Impact of land use change and urbanisation on urban heat island in Lucknow city, Central India: A remote sensing-based estimate. *Sustainable Cities and Society, 32*, 100–114. https://doi.org/10.1016/j.scs.2017.02.018

Taleb, H. M., Kayed, M., & Baba, F. (2024). Genetic Algorithm for Optimizing Urban District and Block Morphology to Minimize Solar Radiation Access and Maximize Building Floor Area in the UAE. *Buildings*, *14*(12), 3898. https://doi.org/10.3390/buildings14123898

Tay, J., Ortner, F. P., Wortmann, T., & Aydin, E. E. (2024). Computational optimisation of urban design models: A systematic literature review. *Urban Science, 8*(3), 93. https://doi.org/10.3390/urbansci8030093

Turrin, M., Von Buelow, P., & Stouffs, R. (2011). Design explorations of performance driven geometry in architectural design using parametric modeling and genetic algorithms. *Advanced Engineering Informatics*, *25*(4), 656-675. https://doi.org/10.1016/j.aei.2011.07.009

Vizotto, I. (2010). Computational generation of free-form shells in architectural design and civil engineering. *Automation in Construction, 19*(8), 1087–1105. https://doi.org/10.1016/j.autcon.2010.09.004

Wang, S., Zhang, D., Hao, X., Liang, J., & Li, S. (2025). Data-driven optimization design method and tool platform for green residential area layout. *Journal of Asian Architecture and Building Engineering*, *25*(1), 443–459. https://doi.org/10.1080/13467581.2025.2459824

Wang, Y., & Chai, H. (2025, July). A Framework for Computational Urban Design: Model and Applications. In *International Symposium for Intelligent Transportation and Smart City (ITASC) 2025 Proceedings: Branch of ISADS (The International Symposium on Autonomous Decentralized Systems)* (Vol. 1407, p. 129). Springer Nature. https://doi.org/10.1007/978-981-96-4702-6_14

Wang, Y., Yan, X., Zhang, X., & Zhang, D. (2025). A multi-objective optimization framework for designing residential green space between buildings considering outdoor thermal comfort, indoor daylight and Green View Index. *Sustainable Cities and Society, 119*, 106045. https://doi.org/10.1016/j.scs.2024.106045

Wolpert, D. H., & Macready, W. G. (1997). No free lunch theorems for optimization. *IEEE Transactions on Evolutionary Computation*, 1(1), 67–82. https://doi.org/10.1109/4235.585893

Wortmann, T. (2017a). Model-based optimization for architectural design: Optimizing daylight and glare in Grasshopper. *Technology| Architecture + Design, 1*(2), 176–185. https://doi.org/10.1080/24751448.2017.1354615

Yang, L., Chang, H. T., Ma, H., Wang, T., Xu, J., & Chen, J. (2023). Applying Evolutionary Computation to Optimize the Design of Urban Blocks. *Buildings*, *13*(3), 755. https://doi.org/10.3390/buildings13030755

Zhang, L., Zhang, L., & Wang, Y. (2016). Shape optimization of free-form buildings based on solar radiation gain and space efficiency using a multi-objective genetic algorithm in the severe cold zones of China. *Solar Energy, 132*, 38–50. https://doi.org/10.1016/j.solener.2016.02.053

Zhang, R., Waibel, C., & Wortmann, T. (2020). Aerodynamic shape optimization for high-rise conceptual design. *Proceedings of the eCAADe*, *38*, 37–45. https://doi.org/10.52842/conf.ecaade.2020.1.037

Zhang, Y., Murray, A. T., & Turner Ii, B. L. (2017). Optimizing green space locations to reduce daytime and nighttime urban heat island effects in Phoenix, Arizona. *Landscape and Urban Planning*, *165*, 162-171. https://doi.org/10.1016/j.landurbplan.2017.04.009

Zhao, S., & Zhang, X. (2023). Energy consumption and heat island effect mitigation analysis of different roofs considering superposition coupling. *Frontiers in Energy Research, 10*, 1047614. https://doi.org/10.3389/fenrg.2022.1047614

Zhu, B., Han, Z., & Pouramini, S. (2024). Optimization of urban buildings form using a modified competitive search algorithm. *Journal of Cleaner Production*, *434*, 139615.https://doi.org/10.1016/j.jclepro.2023.139615